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Review

Comparative Analysis of Soil Fertility, Productivity and Sustainability of Organic Farming in Central Europe—Part 1: Effect of Medium Manifestations on Conversion, Fertilizer Types and Cropping Systems

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Abstract: Organic farming systems have become widespread in recent decades due to their popularity with consumers and their beneficial effects on the environment and biodiversity. Through the increasing number of available studies from farm surveys and comparable results from long-term field trials, the various real existing forms and intensities of agricultural management were subjected to a closer examination in this review. In this paper, the mean characteristics and the range of variation in crop productivity, crop quality and soil fertility as well as the importance and the extent of environmental impacts are comparatively analyzed. From widespread cultivation systems and forms of nutrient management from Central Europe with a focus on Germany, the following fields of influence were investigated and conclusions for the future optimal design of organic cultivation methods were listed: site, soil conditions, climate, phases of conversion and consolidation, crop rotations and farm structures, application of organic and mineral fertilizer types.

Keywords: Central European countries; organic farming cultivation systems; farm and farm-field plot analysis; long-term field trial analysis; organic fertilizer types; medium fertilizer input; medium legume N_2 fixation input; conversion and long-term trends on crop yield; soil fertility and environment

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1. Introduction

In organic farming systems [1,2], mineral nitrogen fertilizers, which are considered effective means of increasing yields in conventional farming, are generally avoided. Instead, the potential for N_2 fixation is used by supplying nitrogen through the cultivation of legumes in wide-ranging crop rotations. Where possible, nutrients from manure, slurry or other organic fertilizers produced in the farm cycle are used for plant nutrition. In animal husbandry, there are upper limits for the number of animals, which are closely linked to the size of the farm area. In this way, nutrient surpluses can be avoided as far as possible. Organic farming is expected to have beneficial effects not only on the environment and biodiversity, but also on consumer consumption habits and demand. This form of cultivation enjoys high popularity and has increased significantly in recent decades [3–5].

Parallel to the spread of organic farming, experimental scientific processing also emerged, with particular reference to the conduct of long-term field trials. In some early trials, test elements with conventional and alternative organic cultivation contents of different intensities were compared: Järna, Sweden: 1958–1990 [6,7]; Therwil, Switzerland: from 1978 [8,9]; Darmstadt, Germany: from 1980 [10–12]. Further descriptions of long-term experiments were made by [13–15].

On the other hand, on-farm studies were also undertaken early on, often focusing on topics with practical relevance to soil fertility and nutrient management [16–30].

In recent decades, extensive comparative studies between conventional and organic farming have also been conducted, in which a wide range of characteristics regarding the productivity of the farming system, the fertility of the soil, and, increasingly, environmental aspects have taken a central position [31–38].

For example, beneficial environmental effects of organic farming are based on reduced nutrient discharge into ground and surface waters. In the case of the nutrient nitrogen, it has been shown that this results in an improved relationship between supply and removal, which increases nutrient efficiency accordingly. However, due to the system-related control mechanisms mentioned above, yields remain at different levels depending on the crop species, but at a comparatively lower level overall. In recent experiments, therefore, cultivation systems of the ecological practice itself have increasingly been subjected to intensive testing, whereby topics concerning regional adaptation strategies and the further development of organic systems have gained in importance [14].

Due to the increasing amount of results becoming available from long-term trials and farm surveys, it was possible to examine the various existing forms and intensities of land cultivation in more detail and, in addition to the yields and vitality of the crop species, the quality of the harvested products and the soil fertility, also to show the significance and extent of environmental effects in a comparative analysis. Based on the abundance of data, conclusions could be drawn for the future optimal design of organic cultivation methods with their short-term and long-term effects on soil, plant, and atmosphere. Special attention was paid to the following areas of influence:

- Site, soil, climate.
- Phases of conversion and development over time.
- Cultivation system, crop rotation and farm type.
- Organic and mineral fertilizer type and intensity.

This review presents results on the average manifestations of organic farming systems in Central Europe by summarizing existing investigations and studies with a focus on the last 20 years. In the second part [39], organic farming systems with widely varying intensities are presented, ranging from relatively extensive cash crop systems to livestock-rich forage production systems, with emphasis on the use of organic fertilizers and the extent of legume cultivation.

2. Description of Participating Long-Term Experiments

The data originated from Central Europe with an emphasis on Germany. The main long-term trials were described in Table 1 with their mainly used experimental variants. The mean composition of the organic fertilizers primarily spread and used was listed in Table 2.

Table 1. Location, site, and management factors of the long-term field trials depending on soil type.

	Light Soils (S, Sl, lS) (1)			**Medium-Heavy Soils (SL, sL, L, lT, T) (1)**			
				Location			
Country	**D**	**D**	**D**	**D**	**D**	**D**	**CH**
Test Site	**Spröda**	**Gülzow**	**Güterfelde**	**Methau**	**Roda**	**Hennef**	**Therwil**
Altitude (m)	120	5–10	41	265	224	65	300
Type of trial	Exact trial	Large plot trial	Exact trial	Exact trial	Large plot trial	Exact trial	Exact trial
				Climate			
Mean annual precipitation (mm)	547	542	545	693	711	850	792
Mean annual temperature (°C)	8.8	8.2	8.9	8.4	8.6	10.3	9.5

Table 1. *Cont.*

	Light Soils (S, Sl, lS) (1)			Medium-Heavy Soils (SL, sL, L, lT, T) (1)			
Soil							
Soil type (1)	Sl	S–SI	SI	L	L	slU	L
Clay content (%)	5–7	6–8	4	15–18	12–15	12	17
Specific gravity (g cm^{-3})	1.7	1.5	1.6	1.3	1.3	-	1.4
Soil quality index (2)	30/33	33–38	23–31	70/63	68	50	-
pH value	5.0	6.5	6.2	5.7	6.0–6.6	5.3	6.3
Cultivation and fertilization system							
Cultivation system	Typical crop rotations for forage production (by-products removed), market crop systems (by-products remain, clover-grass mulching)	Site adapted crop rotations	Crop rotations typical for the site, plowing and non-turning tillage	Typical crop rotations for forage production (by-products removed), market crop systems (by-products remain, clover-grass mulching)	Site adapted crop rotations without livestock and with livestock	Crop rotations with biodynamic preparations	Comparison between conventional and organic crop systems
Fertilization system (fertilizer types, amount (3))	Stable manure, slurry, green manure 0.0, 0.5 and 1.0 LU ha^{-1} N-mineral fertilization	Stable manure 0.8 LU ha^{-1}	Stable manure 0.0 and 0.7 LU ha^{-1}	Stable manure, slurry, green manure 0.0, 0.5 and 1.0 LU ha^{-1} N-mineral fertilization	Stable manure, slurry 0.0 and 1.0 LU ha^{-1}	Compost, stable manure, additives 0.0 and 1.1 LU ha^{-1}	Types of stable manure, composted manure, slurry 0.0, 0.6 and 1.2 LU ha^{-1} N-mineral fertilization
Crop rotation							
Clover-grass, grain legumes (share per crop rotation)	Clover-grass 33%	Clover-grass, grain legumes 33%	Clover-grass, grain legumes 29%	Clover-grass 34%	Clover-grass, grain legumes 50%	Clover-grass, grain legumes 33%	Clover-grass, grain legumes 43%
Cereals (share per crop rotation)	Winter and spring wheat 34%	Winter and spring cereals 50%	Winter rye, triticale 43%	Winter wheat, triticale 33%	Winter wheat, spring barley 33%	Winter wheat, winter rye, spring wheat 50%	Winter wheat 28%
Root crops, corn, field vegetables (share per crop rotation)	Potatoes, corn 33%	Potatoes 17%	Potatoes, corn 28%	Potatoes, corn 33%	Potatoes 17%	Potatoes 17%	Potatoes, corn 29%
Literature sources	[40–43]	[44]	[45,46]	[40–43]	[47]	[48,49]	[8,9,50]

(1) Soil types: S = sand, Sl = poor loamy sand, lS = loamy sand, SL = high sandy loam, sL = sandy loam, L = loam, lT = loamy clay, T = clay, U = silt. (2) Soil quality index: https://www.gesetze-im-internet.de/bodsch_tzg_2008/BJNR317600007.html (accessed on 21 July 2022). (3) Fertilization systems: livestock units (LU), 1 LU ha^{-1} = 60 kg N ha^{-1} year^{-1}.

Table 2. Average nutrient contents of the organic fertilizers used.

Fertilizer Type	DM [% FM] [(1)]	N [% DM]	NH_4-N Part [% of N]	P [% DM]	K [% DM]	Mg [%DM]	C:N Ratio
Composts, including Stable manure compost	35–70	0.9–2.0	4–13	0.3–0.6	1.0–2.0	0.4–0.5	16.0–30.0
Stable manure	21–26	2.1–2.7	15–17	0.4–1.2	2.4–4.3	0.4–0.7	14.3–17.7
Cattle slurry	6.6–6.9	4.2–5.5	38–62	0.9–1.0	3.6–4.1	0.7–0.9	7.7–7.8
Green manure (clover-grass)	19.9–20.0	2.2–2.7	0–3	0.2–0.3	2.2–2.7	0.2–0.3	15.1–16.1

[(1)] DM: dry matter; FM: fresh matter.

3. Description of Farm Surveys

The studies were carried out in Central Europe, with a focus on Germany, as surveys from farms, on permanent residual areas and other areas of arable land, different types of farms with and without livestock (excluding pure vegetable farms, special crops, greenhouse cultivation of horticulture) including the use of farm records from field plot indexes and stable books of organic farming. The scope of the study generally covered three to six years at the area level, if possible, at least one complete crop rotation, or at the farm level at least two full crop years of subsequent studies (total of approx. 423 farms):

- Germany: Ref. [30] Federal state of Saxony, 32 farms, 1200 arable and grassland plots.
  Ref. [51] calculation for federal state of Hesse.
  Refs. [29,52] nine federal states, approx. 360 farms, approx. 7460 arable and grassland plots. Used data from the following papers: Refs. [53–71].
  Ref. [72] 20 farms.
  Ref. [73] five federal states, 28 farms.
- Austria: Ref. [74] two farms.
- UK: Ref. [25] nine farms; Ref. [75] two farms.
- Norway: Ref. [76] 30 farms.

The values determined in the studies of agricultural practice and in statistical surveys for Germany and for the European Union [77] on the average cultivation sequences and animal husbandry scope of organic farming are presented in Table 3. There are good possibilities for comparison between the cultivation composition of legumes and non-legumes in the crop rotations tested in the long-term trials and the scope of application of organic fertilizers (Tables 1 and 3).

Table 3. Mean crop composition of organic farming practices in Germany and the European Union.

Attribute	Studies of Organic Farming			Statistical Surveys		
Number	1	2	3	1	2	3
Forage and grain legumes (%)	40	33	39	42	40	approx. 48 [(1)]
Cereals (%)	51	-	48	47	48	40
Root crops (potatoes, corn, oilseeds, field vegetables) (%)	9	-	13	11	12	12
Livestock (LU ha^{-1})	0.6	-	0.3	-	0.5	0.4
Organic fertilization (kg N ha^{-1} $year^{-1}$)	62	44	22	-	30	-
Literature sources	[73]	[29]	[30]	[78]	[79]	[77]

[(1)] The values documented for the EU for forage and grain legumes also include non-leguminous forage crop areas such as silage or green corn.

4. Description of Soil and Plant Investigation

Soil investigation methods:

- NH_4- and NO_3-nitrogen (N) in 0.0125 molar calcium chloride ($CaCl_2$) solution (N_{min}) 0–90 cm soil depth or depth drilling 90–200 cm with ram core probes (6 cm diameter) [80].
- Soluble sulfur (S_{min}) 0–90 cm depth according to [81].
- pH 0–30 cm soil depth in 0.01 molar $CaCl_2$ [82].
- Soluble phosphate (P) and potassium (K) extraction with diluted lactate solutions (DL, CAL) at 0–30 cm soil depth [83,84].
- $CaCl_2$-available magnesium (Mg) at 0–30 cm soil depth [85].
- Total organic carbon (C_{org}) with elemental analysis (DIN ISO 10694) at 0–30 cm soil depth.
- Total N (N_t) according to [81] at 0–30 cm soil depth.

For methods of plant examination, see [43].

5. Calculation Tools

Methods of balancing:

- Legume N_2 fixation: mostly special methods for suitability in organic farming [86].
- (Aggregated) field or area balances, in exceptional cases farm gate balances for the nutrients N, S, P, K, Mg, according to PARCOM guideline as gross balancing inclusive deposition of nutrients (N, S) via atmosphere, possibly non-legume N fixation, supply via transplant and seed, 100% crediting of organic fertilizers, in case of farm gate balance possibly minus N stable losses [87,88].
- Methods of N-efficiency calculation according to [43].
- Calculation of the N-mineralization according to [89] by using the model CCB (Candy Carbon Balance).
- Soil organic matter balance ("humus balance") in humus equivalents (HEQ) with different methods [90–92].
- Application of PC programs for calculation of legume N_2 fixation, balancing and fertilizer recommendation: BEFU, part of organic farming [88] or other models and methods e.g., REPRO [93].
- Calculation of grain equivalents (GE) of the crop species according to [94].

Methods of result evaluation:

- Designation of value ranges of undersupply (A, B), optimal supply (C) and oversupply (D, E) according to VDLUFA in Germany (https//www.vdlufa.de accessed on 1 July 2022) or adapted to organic farming conditions for plant-available or soluble soil nutrients (P, K, Mg) as well as pH values, evaluation of N and S balance (including deposition) and supply level of decomposable organic matter (humus balance) according to [95].
- Measurement and evaluation of the yield loss of the crop types based on the minimum law of Mitscherlich [96] according to [95].
- Assessment of yield risk respective to errors in crop rotation design according to [30].

6. Biometric Evaluation Methods

Statistical analysis was performed using the SPSS program system by determining mean, weighted mean (MV), rate of change per time unit, standard deviation (s), mean standard deviation (ms). Other statistical procedures were used: correlation (r), simple regression, multiple linear regression analysis with coefficient of determination (R^2, mR^2) and slope (b), significance limits: 10% = (*) ($p < 0.10$); 5% = * ($p < 0.05$); 1% = ** ($p < 0.01$); 0.1% = *** ($p < 0.001$).

7. Data Scope, Processing, and Quality

The procedures and methods used to collect and prepare data from documented long-term trials and farm surveys are very diverse and, sometimes of different quality, which often limits responsible use. Data from exact trials often have high statistical reliability, but often do not describe the situation in agricultural practice sufficiently well. Data from agricultural practice are used widely, are often only available through intimate or internal contact, but often do not have good statistical reliability and scientific publication.

The validity of some of the data and discussion contributions often had to be restricted or, in some cases, considerable effort was required for reorganization and conversion as the methods and data of the long-term experiments and farm surveys documented or used often showed considerable deficiencies due to the following reasons:

- Significant decrease in the minimum number of experimental years or soil depth investigated to reliably document certain characteristics, such as results of C_{org} content or humus balancing [97–99].
- Number of years or use of incomplete crop rotation cycles too low to document soil or plant data and nutrient balancing calculations, which is especially important in organic farming due to the heterogeneity of crop rotations [73,100].
- Use of inadequate or non-standard forms (e.g., according to PARCOM guideline [87] or unusual forms of nutrient balancing [62,100–105].
- No or too little reference to area or farm level or limitation of the investigation methods to nutrient and humus balances under extensive non-consideration of soil investigation results and other sustainability indicators of soil fertility for important statements on nutrient management of farms [73,106,107]. For example, on the Gladbacherhof in Germany, yield-limiting nutrient deficiencies could have been detected and corrected earlier by applying commonly used prophylactic nutrient management practices (see [108,109]).
- Partial use of very imprecise methods for the calculation of leguminous N_2 fixation, for humus balancing or N_t soil balance, which, especially in the organic farming forms of application, show only low statistical certainties or hardly any correlation with the reality. Especially in conventional practice, common forms for calculating the N_2 fixation of legumes show no correlation with results from exact experiments [110]; see [86]. Extreme and strongly fluctuating findings exist between corresponding results for humus balancing, e.g., with the HE method, compared to C_{org} content changes in validation experiments [65,98,111]; see [112].
- Use of methods with too shallow sampling depth below the root horizon (e.g., suction cups, lysimeters) to assess the potential for translocation and leaching of nutrients into the subsoil [57,58,113–116]. Not only due to the periodic cultivation of deep-rooted crop species, these methods are unsuitable for application in organic farming in particular.
- Statements, e.g., on differences between cropping systems and other organic farming practices, derived (in part) from exact trials [15,31,35,36,38,105].
- Emphasis on short-sighted measures and successes based on trial results, e.g., according to a first trial phase, without corresponding consideration of results or findings from long enough long-term trials or farm management practices in some current concepts on plant nutrition and fertilization in organic agriculture [117,118].

8. Effect of the Phase of Conversion from Conventional to Organic Farming Practices

After the conversion to organic production methods, certain changes occur in principle not only on farms but also after the start of corresponding long-term trials. Depending on the intensity of the average (conventional) previous cultivation, various characteristics are changed to different extents after the start of organic cultivation. For example, the yield developments of the crop species after conversion have been studied quite extensively and well in agricultural practice. Particularly, as a consequence of the omission of mineral N fertilization, yields drop to varying degrees depending on the crop species; initially very markedly in the first 2–3 years of conversion, and then, depending on the new management conditions, in some cases they slowly increase again in subsequent years [119–123].

According to evaluations by [124], organic cultivation methods show yield differences of approx. 19%. Kravchenko et al. [125] report 20–25% yield loss from results of exact trials, higher values between 27–34% are reported from practical surveys. Alvarez [126] compares the yield loss with the difference in production level in a meta-study. According to this study, yields are 25% lower in organic farming, while the intensity level of soil use (years with harvest crop in relation to rotation duration), however, is 29–44% lower than in conventional farming. A further overview of differences between organic and conventional farming methods is given by [36,38,127–131]. However, it is often not possible to distinguish in detail whether the data originate from agricultural practice or from special exact trials.

The extent of the average drop depends in particular on the site and soil type, the level of initial organic and mineral nutrient supply and the type of crop grown (Table 4). For example, it is regularly found that higher levels of N fertilization, such as in Europe, show a more significant drop in yield after conversion than usually lower levels in the U.S. [132]. Crop species with high N fertilizer requirements or even on crop protection products, such as winter wheat and winter barley or potatoes, are more affected than, for example, triticale, oats, corn, sugar beets, grain, and forage legumes. In this context, more reliable data are often obtained from practical surveys, which are used, for example, for precise economic evaluations by the responsible service institutions [133]. Thus, the average difference between conventional and organic cultivation is about 30%; over time, these differences have apparently become somewhat larger (Table 4).

In contrast, relevant studies from long-term field trials and other data evaluations, some of which are worldwide, determine significantly higher yields with a drop of only 19%, usually with good statistical reliability, but which often do not reflect the situation in organic farms and therefore cannot be recommended for practical use. The conclusion from this exemplary comparison is that it is necessary to use survey data from diverse agricultural practice as far as possible for these evaluations. Data originating from trials must be scrutinized critically according to their exact intensity and methodological processing in order to enable an overall description and analysis of organic farming that is as accurate as possible (see further examples in chapter 7).

Table 4. Yield differences between conventional and organic cultivation of crop species determined from field surveys and long-term trials (conventional level = 1.0).

Study No.: Crop Species	1a [(1)]	1b [(2)]	2	3	4	5	Farm	6	7	8	9	10	Trials and Other Sources
	1995–2005	1995–2005	2012–2020	2003–2016	2016	-	MV, (s)	2014	2004–2010	1961–2009	2001–2013		MV,(s)
W. wheat	0.56	0.59	0.47	0.64	0.58	0.62	0.58 ± 0.06	0.71	0.73	0.62	-	0.71	0.69 ± 0.05
W. rey	0.56	0.59	0.54	0.61	0.53	-	0.57 ± 0.03	1.06	0.76	-	-	-	0.91
W. triticale	0.68	0.71	0.60	0.69	0.67	-	0.67 ± 0.04	-	-	-	-	-	-
W. barley	0.50	0.53	0.54	0.59	0.57	-	0.55 ± 0.04	0.67	0.69	0.70	0.67	0.74	0.69 ± 0.03
S. barley	0.56	0.60	-	0.67	0.62	-	0.61 ± 0.05	-	-	-	-	-	-
Oat	-	0.74	0.76	0.68	0.66	-	0.71 ± 0.05	0.83	0.85	-	-	-	0.84
Corn	0.75	0.78	-	0.64	-	0.73	0.73 ± 0.06	0.73	0.89	0.85	1.20	0.76	0.89 ± 0.19
Peas	0.73	0.75	0.60	0.57	0.72	-	0.67 ± 0.08	0.89	0.85	-	0.80	-	0.85 ± 0.05
Field beans	-	-	-	0.71	0.79	-	0.75	0.77	-	-	-	-	0.77
Soya beans	-	-	-	0.93	-	0.78	0.86	0.69	0.92	0.90	-	0.96	0.87 ± 0.12
W. rape	0.74	0.78	-	-	0.71	0.67	0.73 ± 0.05	-	0.74	-	-	-	0.74
Potatoes	0.54	0.54	0.53	0.51	0.64	0.69	0.58 ± 0.07	0.68	0.70	-	0.82	0.65	0.71 ± 0.07
Sugar beet	0.90	0.95	-	0.73	-	0.75	0.83 ± 0.11	-	-	-	-	-	-
Forage legumes, legume-grass	0.95	1.00	-	-	0.85	-	0.93 ± 0.08	0.98	0.89	-	-	0.87	0.91 ± 0.06
Mean value	0.68	0.71	0.58	0.66	0.67	0.71	0.70 ± 0.05	0.80	0.80	0.77	0.87	0.78	0.81 ± 0.04
Location	D	D	D	A	S	EU		U.S.	EU/U.S.	EU/U.S./World	NL	EU/U.S.	
Farm survey	X	X	X	X	X	X		X	X ?	(X)			
Trial survey									X	X	X	X	
Literature sources	[134]		[135]	[136]	[137]	[138]		[139]	[140]	[36]	[141]	[15]	

[(1)] = light soils; [(2)] = medium-heavy soils.

This general development of the yield level of the crop types can also be confirmed here after the start of special trials [142–145]. Thus, compared to the preceding high conventional fertilization and yield level, the level of crop yields had initially dropped significantly even after the start of many of the long-term trials presented here. In addition to yields, the following characteristics also initially dropped in the course of the organic trials, depending on the outgoing management level: Components containing N (soil: N_{min}, N_t; plants: nitrate, crude protein), plant-available basic nutrients in the soil (P, K, Mg), and pH value [43,50,146–153].

These changes in soil chemical fertility after conversion to organic farming are also registered on farms [19,20,154,155]. According to reports by [18], the very low nutrient contents of relatively old organic farms apparently still originate from a time when conversion took place before the corrective fertilizer application phase in conventional farming. According to studies by [156], after cessation of mineral N fertilization and reduction in total N supply by 60–100 kg N ha^{-1} year^{-1}, there was a decrease of 37 kg N ha^{-1} in NO_3-N amounts from 0.6–5.0 m soil depth in the first 3–4 years after conversion. The main removal of N by plants has been found in the rootable space down to below a depth of 2.50 m. The reduction in the N leaching potential can be considered one of the most striking results after conversion, especially to crop rotations with periodic cultivation of deep-rooted crop species, such as alfalfa grass.

Due to the high level of mineral and organic fertilization, which often lasted for decades, there was a significant increase in the N_t content under conventional management and thus also a narrowing of the C:N ratios of the soils [157,158]. This is the basis for the negative changes in the soil N_t pool often analyzed later after conversion. Furthermore, the analyzed nutrient balances for N and the calculated N efficiencies are closely dependent on the total nutrient supply. These interrelationships are then often the basis for the observed relations between nutrient balances and soil N_t changes, and therefore give little concern to an "efficiency-sustainability dilemma" in organic farming systems [159].

In contrast, the C_{org} contents as well as the C:N ratios in the soil of the field experiments presented in more detail here have increased from the beginning compared to conventional pre-cultivation, as can also often be observed in organic farms after conversion. Thus, according to studies by [63,160,161], there are differences in humus balances between conventional and organic management of approximately 50–100 humus equivalents (HEQ) ha^{-1} or 0.03–0.06% higher soil C_{org} contents in agricultural practice. After a worldwide evaluation of soil data, which, however, also included many results from special comparative trials as well as data from other regions, a mean difference of 0.18% C_{org} was determined. Only in farming systems with (land independent) high livestock production can decreasing C_{org} contents also be analyzed after conversion to organic farming [35].

On average, the cultivation methods have higher C_{org} contents as, overall, there is usually a higher supply of organic matter. This occurs, on the one hand, through the supply of organic fertilizers and, on the other hand, despite the lower yield level, usually through crop rotations with forage legumes in mixtures with grass species that have high proportions of crop and root residues [162]. In contrast, with accurate analyses and sufficiently long trial duration of a conversion to reduced tillage practices, there is usually no increase in the C_{org} content, but merely a redistribution of the organic matter in the depth profile of the soil [163,164].

A number of studies have experimentally investigated how the organic matter stocks of soils will change in the course of the impending climate change. In most regions of Europe, a decrease in the C_{org} content is to be expected, in particular due to an increase in temperatures, and in many sites also due to a decrease in precipitation [165–168]. When maintaining an average conventional management, for example, an increase in temperature between 1.0–2.4 °C and a decrease in precipitation up to 125 mm per year until 2050, could lead to a calculated drop of the organic matter contents in three regions of eastern Germany between 0.04% C_{org} on loess soils of the lowlands, 0.15% C_{org} on light soils and of 0.43% C_{org} in arable soils of the mountainous areas.

By converting to organic farming methods with approx. 37% legumes in the crop rotations and 0.4 LU ha^{-1} livestock, as is common in many regions, this drop of 0.05% C_{org} on the loess soil can be more than balanced out. On sandy soils, however, as a result of the low yield potential according to these calculations, conversion would only lead to a small increase in C_{org} content of 0.02% and in mountain sites of 0.08% C_{org}, so that the climate-induced decrease could hardly be compensated [134,161]. Studies from the Netherlands reveal similar results [169,170], while comparative results from certain long-term experiments show in part significantly higher organic matter enrichments [171–173]. In these experiments, it seems that the organic practice cannot be represented accurately enough. According to [174], the focus should not be so much on the influence of climate change on the organic matter contents but on the effect on its function in the soil.

Even by participating in programs of the four per mille initiative [175], e.g., for 20 years, to actively address climate change by organic matter increase only an intermediate C_{org} increase of about 0.1% would be possible, which would also compensate the negative influence of climate change only to a minor extent [176]. Many of the targeted hopes and projections for organic matter enrichment are unlikely to be met under real-world practice conditions [177–179]. Studies on the climate impact of agricultural practices, with high ranges of variation, essentially show a reduction in trace gases after conversion and maintenance of organic farming management when considered on an area basis, and also in some cases when evaluated on a product basis. These results from conventional and organic farms and additional investigations can be examined in further summarized studies [73,180,181].

9. Effect of the Phase of Consolidation of Organic Farming Management

9.1. General Remarks

After the conversion time, a period of up to 20 years can be observed on the young organic farms, during which a phase of consolidation of the achieved yields of the crop species and soil fertility can be noted. This time period depends, among many other aspects, mainly on the site and the individually realized intensity level (nutrient export, level of livestock and cultivation of legumes) of the farm [121,122]. For a precise description of these change processes, certain long-term field trials are again advantageous if the respective cultivation spectrum and intensity level correspond well with those of the farms. In particular, field trials that have been set up on different sites for cultivation optimization and have durations of at least between 10–20 years appear to be suitable for this purpose. These trials then no longer include individual variants as in the more traditional organic trials, in which general differences between conventional and organic cultivation methods are shown [14].

To describe the average cultivation intensity of existing organic farms, two long-term trials on sandy and loamy soils from eastern Germany can be used, which show an average forage legume range of about 33% and an input of organic fertilizers from stable manure and slurry of 30–40 kg N ha^{-1} $year^{-1}$. Extreme variants between pure forage and market crop variants can also be depicted. Further descriptions of comparable experimental setups can be found in Table 1.

If the results from the first eight years (=first phase of the long-term experiments, [40,41,182]) are compared with those from the second phase [43], then, in addition to many largely consistent results, a number of in part clearly contradictory results have also been registered, which can be presented as follows:

Time period:	1st trial phase (8 years)	2nd trial phase (6–8 years)
Comparison between forage crop (FCP) and market crop production (MCP):		
-Yield level of crop species:	FCP higher than MCP	MCP higher than FCP.
-Development C_{org} content soil:	FCP higher than MCP	MCP higher than FCP.
-N-translocation subsoil:	Low, no differences	MCP slightly higher than FCP.
-Crude protein in wheat grain:	MCP higher than FCP	Loamy soil: FCP higher than MCP. Sandy soil: MCP higher than FCP.
Influence of increasing organic fertilization:		
-Yield level of crop species:	Relatively small differences	Larger yield differences.
-N-translocation subsoil:	Low, hardly any differences	Increasing with fertilizer level.
-Development N_t content soil:	Partial decrease	Increase in contents.
Comparison of fertilizer types:		
-Yield level of crop species:	Slurry often higher than stable manure	Stable manure often higher than slurry.
-Development C_{org} content soil:	Stable manure increase	Stable manure, green manure clear increase,
	Slurry partial decrease	Slurry small increase.

Some differences can certainly also be explained by the improved data situation due to the extended test period, which is, for example, not only important for the assessment of the C_{org} content of the soil [183]. However, many other differences between the experimental phases remain, so the question must be clarified as to why these partly contradictory developments could be documented.

Using the example of the different chronological development of the yields of the crop species between the cultivation systems of forage and market crop production, these different developments in the long-term trials can be clarified today. In addition, parallel developments of yields can be observed at both sites, according to which at the beginning of the trial the yields of the forage cultivation variants were often higher than those of the market crop variants, as has also already been described, for example, by [184]. However, with increasing experimental time, the market crop variants were characterized by a more significant increase in yield. Differences between systems with leaving or removal of the clover-grass growths have also been investigated by other authors [185].

Due to the market crop system, the following amounts of organic material (2–3 clover grass growths, by-products of the cultivated cereals in the form of straw) remained on the fields each year: Loam soil 5.8 t clover-grass DM, 2.1 t straw DM ha^{-1}; sandy soil: 2.3 t clover-grass DM, 1.0 t straw DM ha^{-1}. Due to the wide C:N ratios in straw, microorganisms in straw decomposition use the soil reserves of plant-available N. Therefore, the suspicion arose early on that straw in particular could have negatively influenced the yield performance of direct subsequent crops, such as corn cultivation, via N immobilization.

Through a separately designed trial on straw and green manure, the extensive experimental knowledge obtained in conventional farming could initially also be confirmed for the conditions of organic farming. According to this, a considerable supply of wheat straw, for example, leads to the following changes in the soil and on the yield performance of the direct subsequent crop oats [186]:

- N_{min} spring (0–60 cm depth): -6 kg N ha^{-1} (=-12%).
- Green manuring (legumes, grass): Increase N_{min} content without closing the gap:
- +14 kg N ha^{-1} (=+27%).
- Grain yield oats: -4 to -5%.
- Straw yield oats: -10%.

Altogether, the increase in N_{min} amounts due to the remaining clover-grass growth (mulching) and the reduction in N_{min} amounts due to the straw additions are likely to almost compensate each other. In the trials, only slightly higher or no higher N_{min} levels were analyzed overall on the market crop plots on both experimental sites. Combinations of straw and green manure are therefore also considered favorable in conventional and organic farming to mitigate the short-term negative consequences of straw application. From some experiments it was even concluded that straw and green manure treatments are equivalent to stable manure applications [187].

However, findings from these short-term trials are not necessarily transferable if these measures remain in continuous operation over time, as is usually the case on a farm or even in a long-term trial. For example, ref. [188] was able to determine from results of two long-term trials that negative effects of continuous straw fertilization on crop yields occurred in the early years of the trials in particular. After the start of such a measure, the straw and contained N are initially added in the first years, which leads to a corresponding increase in the soil organic matter reserves. As the duration of the experiment progresses, ref. [189] found that the N fixation by the straw supply is apparently compensated by N release as a result of organic matter turnover at a similar level, so that there appears to no longer be a differential influence on the crop yield.

The reasons for these changes found in the experiments can be largely attributed to the repetitive annual additions of organic materials from various sources. In these natural biological systems, the subsequent decomposition and mineralization of the supplied organic matter is subject to certain laws depending on the level and quality of the materials, the soil type, and the climatic conditions of the site, which can usually be effectively described by exponential mathematical functions [190].

Thereafter, from an addition of organic matter in the first years, a much more significant decomposition takes place, which becomes smaller and smaller in the following years, until in a few decades the entire added organic material of the first year has been decomposed. The decomposed portion from the freshly added (annually) and residual organic matter from previous years becomes larger and larger until the soil organic matter contents do not further increase [191–193]. Therefore, if the experiments are continued according to the experimental plans with a steady supply of organic materials, a cumulative overall effect will occur until an equilibrium state is reached after a few decades, in which the annual amount of added materials is then also completely decomposed each year.

Based on empirical values from the evaluation of long-term experiments, it can generally be assumed under the local turnover conditions that equilibrium is reached after about 20–30 years from a practical point of view. By the following logarithmic function, which was created using the model CCB [193,194], this specific effect on the soil organic matter turnover and mineralization can be described quite well:

- Relative mineralization extent (%) = 27.903ln(x years) + 11.687 ($R^2 = 0.980$, $p < 0.001$).

Since the experiments to be presented here have mostly not yet been carried out for 20 years, an overall effect in the range of 85–95% can already be roughly estimated on the basis of the mathematical function. Using the example of the change in yield, it can thus be assumed that an experimentally determined yield increase or decrease of 2.0 t ha^{-1} will only increase or decrease by a good 0.2 t ha^{-1} until the equilibrium of the investigated cultivation system is reached.

As in the experiments discussed here, this drifting apart of the experimental variants according to the beneficial or unfavorable changes in soil fertility characteristics with increasing experimental duration can also be observed in other long-term trials with corresponding questions [104,195]. This special after-effect of continued cultivation activities (catch crops, green manures, organic fertilizers, straw, and other organic materials) was also investigated in more detail in special field and pot experiments [196]. Möller and Friedel [117] alone attribute only minor importance to these mechanisms for increasing nutrient delivery and efficiency.

9.2. Differences between Forage and Market Crop Systems

In organic farming, two fundamentally different systems of treatment or use of grown organic matter are common:

- Forage production system with livestock: removal of the crop by-products and clover-grass growths.
- Market crop system without livestock: leaving the by-products and clover-grass growths on the field.

In practice, however, mixed forms also occur, e.g., organic fertilizers may or may not be applied in both systems. In special long-term trials, these cultivation forms were simulated on different sites and the changes that occurred in the growing plant material and in soil fertility were continuously recorded [43].

These chronological changes were initially investigated and confirmed in the experiments for many characteristics using a simplified linear approach in the form of a rate of change (Table 5). From the beginning, the accumulating effects due to the differently supplied organic material that are described have to be considered in the experiments. When the by-products are constantly left on the fields, as in the trial variants of the market crop system to be discussed here, there is no supply of nutrients from the outside, therefore intermediate fixation and release of nutrients equalize with time. Only the regular mulching of the clover-grass growths provides an additional input of N to dry matter supply, through the legume N_2 fixation. As a result of these different treatments of the cropping systems, a significantly higher accumulation of C_{org} contents in the soil finally occurred on the pure market crop variants than on the forage croplands.

Table 5. Effects of the supply of organic materials in market crop and forage production systems corresponding to an average by 0.5 LU ha^{-1} $year^{-1}$ on the annual change of certain characteristics from long-term field trials of a loess and sandy soil (accounting period: loess soil = 15 years, sandy soil = 13 years, mean standard error of the regression, ms).

Attribute	Loamy Soil			Sandy Soil		
	Forage Crop	**Market Crop**	**ms**	**Forage Crop**	**Market Crop**	**ms**
Dry matter inputs (clover-grass mulch, straw, organic fertilizers) (t ha^{-1})	0.87	8.76	-	0.98	4.08	-
GE [(1)] yield (t ha^{-1})	0.0983	0.1285	±1.96	−0.0449	0.0677	±2.09
C_{org} (% DM)	0.004469	0.012281	±0.104	0.002321	0.006071	±0.091
N_t (% DM)	−0.000469	0.000094	±0.0182	−0.000571	−0.000393	±0.0183
N mineralization (kg ha^{-1})	1.123	9.799	±63.8	−3.333	2.201	±54.0
N_{min} spring (kg ha^{-1})	0.600	0.080	±25.4	−0.245	1.073	±20.0
N_{min} fall (kg ha^{-1})	1.729	2.160	±15.6	2.312	0.582	±35.6
P_{DL} (mg 100 g^{-1})	−0.092121	−0.034933	±0.67	−0.085469	−0.080729	±0.84
K_{DL} (mg 100 g^{-1})	−0.315089	0.103259	±2.13	−0.395833	−0.044844	±2.33
Mg_{CaCl_2} (mg 100 g^{-1})	−0.035938	0.029018	±0.48	−0.029375	−0.015625	±0.59

(1) GE: grain equivalents.

Based on these results, the additional N introduced via dry matter on the market crop areas largely remained in the soil as organic matter and N_t contents. As a result of these processes, the soluble contents of N in the soil hardly changed between the forage and market crop systems. Due to the simultaneous increase in organic matter turnover over time, there was a steady increase in the amount of nutrient mineralization, so that the plant-available contents of N and in particular of plant-available basic nutrients in the soil of the market crop variants are at a higher level. As a result of this development, the yield potential of the market crop areas, which was initially at a lower level at the start of the trial, has improved over time to such an extent that the yields of the forage cultivation variants have been overtaken by those of the market crop areas.

Thus, the GE yields of the calculated crop rotations generally increased by 0.07–0.13 t ha^{-1} year^{-1} in the considered trial period of 13–15 years, more so on the market crop areas and the loam soil than on the sandy soil. Here, the yield even decreased in the only slightly fertilized forage cultivation variants in the course of the trial. The yield development can be explained quite well by the change in N mineralization. In contrast, the N_t content and the soluble basic nutrients P, K and Mg decreased in most of the variants, especially in the low fertilized forage cultivation plots and on the sandy soil. Only in the heavy loam soil was the annual supply sufficient, which stabilized the N_t values and even slightly increased the K and Mg contents (Table 5).

9.3. Differences between Periodically Applied Fertilizer Types

From the wide range of organic fertilizers, it is still common practice to describe the short-term effects on yield and quality of the crop species, so that they can also be used specifically in organic farming [117]. In contrast, how repeated application of the same fertilizers over many years can affect the cultivated plant species, the soil and the environment is much less well known due to the complex experimental setups (for the composition of fertilizers used, see Table 2).

In a meta-study by [197,198], this differentiated effect of organic fertilizers was investigated after single and after repeated or annual application in long-term trials on the yields and quality of potatoes. After a single application in a comparable amount before potatoes, the following additional yields of organic fertilizers resulted, which can also be assessed via widespread calculation documents for the estimation of the fertilizer effect in the year of application [162,199,200]:

- Composts 100% (=approx. 2.0–3.0 t ha^{-1}).
- Stable manure 115–130%.
- Slurry 150–165%.
- Commercial fertilizers 120–180%.

After regular application of these fertilizers, there is a different increase in soil organic matter content and nutrient mineralization, which finally leads to a similarly high increase in yield of about 4.0–6.5 t ha^{-1} for all fertilizer types tested. These observed changes of different periodically applied fertilizers also take place on practical farms in the first decades after conversion, depending on the site and climate. Since these aspects can be of importance for the general selection of suitable fertilizers according to business management considerations, the changes in the yield effect and in the soil fertility were subjected to a closer examination in special long-term trials for the fertilizers mainly applied in organic farming (Table 6).

The use of the N mineral fertilizer is not allowed in organic farming, as is the case with most of the easily soluble mineral fertilizers [2,201]. Nonetheless, in some test plots this form of fertilizer was compared with the usual fertilizers such as calcium ammonium nitrate (27% N, 10% Ca), whereby the classification as a non-permitted agent could be technically discussed and verified.

According to the annual DM supply of the fertilizers, the change in the soil organic matter stocks and the extent of annual N mineralization as well as the rates of change in GE yields of the crop rotations were calculated over a period of about 15 years from the beginning of the trials. In the forage cropping system, average yields were increased by 0.05 t ha^{-1} in each year after steadily applied stable manure and by 0.03 t ha^{-1} after slurry. In contrast, yields after co-tested N mineral fertilization, with correspondingly higher initial values, only remained relatively stable or dropped slightly. In the market crop system, with a correspondingly higher supply of organic DM, there was an annual increase in GE yields of 0.11 t ha^{-1} after a steady supply of green manure and still an increase of 0.09 t ha^{-1} year^{-1} after N mineral fertilization.

The influence of fertilizers on the change in N_{min} values is also interesting, whereby the effect of N-mineral fertilization on the values in spring and especially also in fall should be noted. In organic farming, N_{min} values remain relatively low even after steady organic fertilization, which can cause N supply deficits in early spring for certain crop species. This might be prevented by N-mineral fertilization, but then also involves an increase in N_{min} values in fall, which is known to contribute to higher N losses over the winter [31,202].

Table 6. Effects of the supply of organic fertilizers and a mineral N fertilizer of comparable application level per year (total N supply) on the annual change of certain characteristics from long-term trials averaged over a loam and sandy soil (mean standard error of the regression, ms).

Attribute	Forage Crop System				Market Crop System		
	Stable Manure	Cattle Slurry	N-Mineral Fertilization	ms	Green Manure (Clover Grass)	N-Mineral Fertilization	ms
Dry matter inputs (clover-grass mulch, straw, organic fertilizers) (t ha^{-1})	2.59	1.20	0.32	-	9.36	5.94	-
GE yield (t ha^{-1})	0.050405	0.027720	−0.002305	±1.95	0.10884	0.088365	±2.05
C_{org} (% DM)	0.0085237	0.00504762	0.00301508	±0.113	0.0106923	0.00974903	±0.086
N_t (% DM)	−0.000087264	−0.000304795	−0.000473095	±0.0184	0.000258364	0.000013455	±0.0203
N mineralization (kg ha^{-1})	0.46000	−1.28550	−1.56050	±24.3	9.60250	5.20100	±94.6
N_{min} spring (kg ha^{-1})	0.4470	0.3105	3.3405	±32.1	0.8650	1.7485	±23.9
N_{min} fall (kg ha^{-1})	1.7470	2.3040	6.4055	±40.6	2.7905	4.9505	±38.3
P_{DL} (mg 100 g^{-1})	−0.0212370	−0.06064772	−0.14228315	±0.75	−0.03615291	−0.11133797	±1.21
K_{DL} (mg 100 g^{-1})	−0.1711695	−0.2613278	−0.4987270	±2.03	0.12385465	−0.2751426	±1.86
Mg_{CaCl_2} (mg 100 g^{-1})	−0.00235201	−0.0085302	−0.06548084	±0.65	0.0087322	−0.05241251	±0.63

Another aspect that has not been so much in the focus until now is the influence of different organic fertilizers on the time-related change of the contents of plant-available basic nutrients in the soil (Table 6). As it is a known fact that there is no supply of these nutrients with N-mineral fertilization, a high annually recorded decrease in these elements has been analyzed. However, even after a steady supply of slurry and, to a lesser extent, after a supply of stable and green manure at an average level, there is a corresponding decrease in the content of soluble P, K, and Mg in the topsoil of the test plots over time. This trend can only be stopped or even reversed by the high DM supply in the market crop variants if a solid organic fertilization is applied additionally.

10. Long-Term Manifestation of Cropping Systems

10.1. Comparison of Cultivation Systems with Different Types of Fertilizers

In order to achieve better comparability via the long-term effects, the absolute and relative differences achieved on average were compared to the long-term standard variants without fertilization (=100%) for a high number of characteristics of a steady fertilization with the tested organic fertilizers as well as with N mineral fertilizer. Based on the total N contents, relatively equal amounts of added N were achieved between the organic fertilizers with average values of 73–78 kg N ha^{-1} $year^{-1}$ (Table 7).

The yield effect of organic fertilizers has been studied and described in detail in many experiments [143,197,198,203,204]. Since a relatively high number of years of the second experimental phase were included in these summarized evaluations, the application of the organic fertilizers only tended to lead to a small differentiating effect on the GE yields of the crop types.

Table 7. Mean differences as well as relative changes compared to no fertilization (standard = 100%) [(1)] of some characteristics after steady long-term application of stable manure, green manure, slurry, and N-mineral fertilizer in the average of the experimental sites.

Fertilizer Type	Fertilizer Supply	GE Yield Crop Rotation	N Removal	N Balance	P Balance	K Balance	Legume N_2 Fixation Per Clover-Grass Year	Crude Ash Clover Grass	N Content Cereals
	[kg N ha^{-1}]	[t GE ha^{-1}]	[kg N ha^{-1}]	[kg N ha^{-1}]	[kg P ha^{-1}]	[kg K ha^{-1}]	[kg N ha^{-1}]	[% DM]	[% DM]
Stable manure	+74.9	+0.66 (~111%)	+9.6 (~109%)	+67.5	+17.4	+96.8	+6.2 (~103%)	+0.49 (~105%)	−0.03 (~99%)
Green manure	+73.2	+0.67 (~112%)	+7.7 (~115%)	+65.0	+6.4	+62.6	+15.3 (~110%)	+0.52 (~106%)	+0.06 (~104%)
Cattle slurry	+78.0	+0.83 (~115%)	+19.0 (~117%)	+63.0	+11.7	+37.1	+13.2 (~105%)	+0.21 (~103%)	+0.04 (~102%)
N-mineral fertilizer	+95.6	+0.58 (~107%)	+19.3 (~120%)	+46.4	−1.0	−7.2	−74.8 (~58%)	−0.20 (~98%)	+0.30 (~115%)
Mean standard deviation (ms)	-	±0.32	±3.4	±3.4	±2.1	±15.4	±3.0	±0.13	±0.04
Fertilizer Type	**Crude Protein Content Wheat**	**Sedimentation Value Wheat**	**Nitrate Content Potato Tuber**	**DM Supply**	**C_{org} Content Trial End**	**Soil Organic Matter Balance**	**N Mineralization**	**N_{min} Spring**	**N_{min} Fall**
	[% DM]	[mL]	[mg kg^{-1} DM]	[t DM ha^{-1}]	[% DM]	[kg HEQ ha^{-1}] [(2)]	[kg N ha^{-1}]	[kg N ha^{-1}]	[kg N ha^{-1}]
Stable manure	−0.20 (~100%)	+3.3 (~109%)	+93 (~145%)	+2.59	+0.080 (~109%)	+269 (~415%)	+30.0 (~145%)	+3.6 (~110%)	+6.4 (~118%)
Green manure	+0.20 (~103%)	+4.4 (~114%)	+143 (~142%)	+2.17	+0.035 (~104%)	+180 (~175%)	+65.2 (~161%)	+9.1 (~126%)	+5.5 (~113%)
Cattle slurry	+0.20 (~102%)	+6.6 (~121%)	+42 (~152)	+1.20	+0.026 (~103%)	+137 (~239%)	+4.6 (~108%)	+2.8 (~106%)	+4.9 (~113%)
N-Mineral fertilizer	+1.50 (~112%)	+22.4 (~175%)	+592 (~393%)	+0.31	+0.018 (~102%)	+87 (~166%)	+1.5 (~102%)	+15.3 (~137%)	+37.3 (~202%)
Mean standard deviation (ms)	±0.23	±1.6	±18.9	-	±0.02	±18.0	±10.6	±3.4	±2.7
Fertilizer Type	**pH Value**	**P_{CAL} Content**	**K_{CAL} Content**	**P_{DL}Translocation**	**K_{DL}Translocation**	**NTranslocation**	**N Leaching**	**N Efficiency (without N_t Soil)**	**N_t Soil Balance**
		[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[kg N ha^{-1}]	[kg N ha^{-1} year^{-1}]	[%, input = 100%]	[kg N ha^{-1} year^{-1}]
Stable manure	+0.03 (~101%)	+0.75 (~118%)	+3.44 (~139%)	−0.002 (~83%)	−0.11 (~100%)	+1.0 (~119%)	+0.56 (~110%)	−34.5 (~65%)	+31.8
Green manure	+0.11 (~103%)	+1.46 (~130%)	+1.89 (~119%)	+0.158 (~113%)	−0.05 (~105%)	+3.5 (~176%)	+1.79 (~206%)	−14.0 (~69%)	+28.2
Cattle slurry	±0.00 (~100%)	+0.46 (~109%)	+0.84 (~110%)	+0.314 (~146%)	+0.17 (~107%)	+5.2 (~135%)	+2.22 (~161%)	−29.3 (~70%)	+27.6
N-mineral fertilizer	−0.04 (~99%)	−0.21 (~95%)	−1.13 (~88%)	+0.337 (~142%)	−0.44 (~94%)	+22.7 (~392%)	+10.85 (~573%)	−20.3 (~75%)	+18.5
Mean standard deviation (ms)	±0.05	±0.19	±0.56	±0.10	±0.14	±2.4	±1.8	±2.0	±7.8

[(1)] By using the absolute or relative values shown, the respective standard value without fertilizer use can usually be calculated. [(2)] HEQ: humus equivalents [92].

Compared to the variants that were constantly not fertilized, only higher GE yields between 0.66–0.83 t ha^{-1} (111–115%) were achieved on average in the crop rotations. In the cultivation of potatoes and maize the increase was 1.08–1.35 t GE ha^{-1} (117–123%), so that these crops responded much better to organic fertilization than the cereals and clover grasses. Stable manure and slurry were characterized by similarly high effects, the additional yields after green manure application were at a somewhat lower level (Table 7).

In these trials, the long-lasting use of N mineral fertilization led to the fact that both the yield increase in the entire crop rotation with 0.58 t ha^{-1} did not turn out very clearly and remained below the values of the organic fertilizers overall, although a somewhat higher fertilization level was applied (Table 7). This depressive effect of N mineral fertilization had occurred in the trials at both sites, especially for the cereals grown.

Furthermore, although there was a slight increase in plant length and N content of the grain due to the fertilizers tested, this was especially true for the N mineral fertilization. As a result of these altered characteristics, there was a decrease in the stability of the cereal stems. Lodging tendency and susceptibility to fungal diseases were the consequences, as has also been repeatedly observed in other conventional cereal trials on N mineral fertilization [43]. Therefore, in order to achieve a yield level comparable to or even higher than organic fertilizers under organic farming conditions, the use of stalk stabilizers and fungicides would be necessary, in addition to the cultivation of short-straw and resistant cereal species.

However, the steady application of N-mineral fertilization was also not convincing for root crops. Compared to no fertilization, the application here led to an increase in yield to only 113%, whereas it was 117% for green manure, 122% for slurry, and 123% for stable manure. It is known that root crops, such as potatoes, respond particularly well to organic fertilization [205]. After high fertilization, shoot growth is forced to realize a good utilization of irradiation in a similar way as after N-mineral fertilization. In contrast, however, the N contents in shoots and tubers and the nitrate values as well as the raw discoloration of the tubers are comparatively low after organic fertilization (Table 7). Therefore, the table and processing quality as well as the storability of the potato tubers are unfavorably influenced after N-mineral fertilization or are to be considered as relatively low [6]. Consequently, with the same yield behavior, potatoes with N-mineral fertilization are also characterized by, in some cases, significantly lower ratings in the quality properties than with corresponding organic fertilization.

In the case of the clover-grass plots, fertilizer was generally applied only in the year of sowing and not in the following main year of use. Nevertheless, a clear effect or after-effect of the fertilizers was also recorded in the average of the cultivation years. Compared to the variants without supply, the yields of clover grass after stable manure increased to 106%, after green manure to 112% and after slurry to 114%. In contrast, the variants with N-mineral fertilization were characterized by the lowest yield effect with only 104% compared to no fertilization.

Due to an important conversion of the stand composition, the N-mineral fertilization had a positive effect on grass growth, so that the clover and alfalfa proportions in the mixture dropped significantly to 63% and the N contents in the mixture also assumed lower values than in the variants without fertilization. In contrast, the legume percentages mostly remained largely stable due to organic fertilization, and the N contents also hardly changed compared to no fertilization. In the trials of [206] with organic fertilization of similar amount (stable manure, slurry), a decrease in the legume content in the mixture by at most 6% was assessed. Nevertheless, there was still an increase in the leguminous N_2 fixation by approx. 13% compared to the variants without fertilization.

Due to these specific influences, the calculated legume N_2 fixation of the clover grass stands shifted strongly. Compared to no fertilization, the highest values in the N_2 fixation as a result of long-term organic fertilization were already reached after relatively low supply of 30–40 kg N ha^{-1} year^{-1}. Solid organic fertilizers were only slightly better than liquid fertilizers such as slurry. While the values increased overall to 103–110% after organic fertilization, there was a severe decrease in N_2 fixation to 58% in the variants with N mineral fertilization compared to no fertilization. Consequently, the mean difference in legume N_2 fixation amounts to almost 90 kg N ha^{-1} per clover-grass year, which is to be regarded as a remarkable value (Table 7).

The estimated values of legume N_2 efficiency, shown as a calculated proportion in the N removals (=100%) of the crop rotation (values in parentheses), developed as follows (%) due to the fertilizers applied compared to the variants without fertilization (=100%):

Fertilizer type	Without fertilization		MV with fertilization
- Stable manure	100	(65)	96
- Green manure	100	(123)	95
- Cattle slurry	100	(84)	85
- N mineral fertilizer	100	(87)	55

According to these extensive evaluations, the solid organic fertilizers have remained relatively stable, with only a slight reduction in the shares of N_2 fixation in the total N removals of the crop rotation. As calculated by [206], there was even no change at all in the proportion of N_2 fixation in the N removal of the crop rotation. In addition to the yields and the legume species, the changes in the proportion of legumes in the legume grass mixture or in reactive N in the soil also have an effect on the level of N_2 fixation in these calculations.

This development is already indicated in the cattle slurry used, with an average decrease in the amount of fixation of N_2 by 15%. In the experiments of [207], a slurry addition led to a decrease in the legume content between 7–13%. Since other types of slurry, such as pig slurry or biogas slurry, have similar nutrient compositions, their long-term application is also likely to lead to negative trends on the N_2 fixation of legumes (see [208]). Influences of different organic fertilizers on legume content and N_2 fixation in legume-grass mixtures have also been identified in other experiments and described as "buffer effects" [151,209].

However, the reduction in the amount and relative share of N_2 fixation in nutrient removal after easily soluble N mineral fertilization far exceeds all other fertilization variants tested here. The extent of the N_2 fixation losses compares well with conventional grassland N application experiments, according to which the first increase stage with 100 kg N ha^{-1} results in a decrease in the white clover fraction and N_2 fixation by 30–100 kg N ha^{-1}, depending on the grassland species [210,211].

This negative influence of mineral N fertilization on the self-regulation of legume stands (see [212]) and the proportion of reactive N in the soil also led to significant shifts between the components of the nutrient balance. Although the N removal rates of the crop rotations investigated increased in the ranking order from stable manure with 109% to green manure and slurry with 117%, the N removal rates were even higher with 120% after N mineral fertilization, although the GE yields remained at a lower level (Table 7).

Through this it can be seen that the N contents have increased significantly on average in the harvested plant materials. For example, after N mineral fertilization, in addition to the maize and root crops (silage maize 124%, grain corn 114%; potato tubers 133%), an increase in the directly fertilized cereal crop grains of 0.30% N in DM (~115%) was also observed, while after organic fertilization, only small shifts from 99% with stable manure to 104% with a steady supply of green manure were recorded (Table 7). After stable manure, there was a change in N levels to 105% in corn and 99% in potatoes, after green manure to 106% in corn and 99% in potatoes, and after slurry fertilization, N levels increased to 107% in corn and potato tubers [43]. Crude protein contents were increased in wheat grain to a similar extent by N mineral fertilization, so that baking properties in the form of sedimentation value could be raised significantly to 175%. Stable manure with 109%, green manure with 114% and slurry supply with 121% also led to an improvement of the sedimentation values of the wheat grains. Only the mineral content in the form of crude ash dropped to 98% after N fertilization, while the organically fertilized variants recorded between 103–106% crude ash (Table 7).

Influences of organic and mineral fertilization on the contents of nutrients in harvested plant products were also found in other long-term experiments [6,10,203,206,213–215]. The effects of widely varying nutrient supply on growth and quality of potatoes and other crops have been described by [216,217].

Due to the evident unfavorable effects of the N-mineral fertilization on the fixation of N_2 and the removed N-quantities by the harvested products, there was only a relatively small increase in the N field balances, by 46 kg N ha^{-1}. In comparison to no fertilization, the determined N balances of the organic fertilization variants with 63–68 kg N ha^{-1} are therefore close to each other, but on a somewhat higher level (Table 7).

The P and K field balances were also clearly increased by the organic fertilizers. However, after singular N supply, a further decrease in the already negative balance values without fertilization occurred. These values show the essential contribution of organic fertilization, not only to the N supply, but also to the supply of other important nutrients (see Table 2). In contrast, the single N-fertilization leads to a direct influence on the N-balances, but due to the higher nutrient removal, a negative influence on the P- and K-balances could be observed.

The values in the nutrient efficiencies obtained on the basis of the usual nutrient balancing initially showed a known ranking, in which slightly lower values were calculated for the organic fertilizers and the highest efficiency values with an absolute difference of 15% for the N mineral fertilization (Table 7). According to calculations by [218], as well as [117,199,219], cropping systems with N-mineral fertilization have apparent utilization rates of 85–95% and systems with organic fertilization of only 50–80%.

In contrast to these differences, however, the N_t values of the soil that were determined also changed in the trials. As an intermediate reserve, this N is stored in the soil organic matter and only becomes available to plants again over time. The N_t differences determined depend on the organic material supplied by the fertilizers. For example, the comparatively high amount of reactive N from mineral N fertilization apparently contributed only slightly to the N_t accumulation in the soil. After accounting for these amounts with the N balances of the fertilizers tested over long time periods, corrected total efficiency values are obtained, which show hardly any differences between the types of fertilizers.

Recent extensive results from long-term field trials with 15–25 years duration on the calculation of nutrient efficiencies of different applied fertilizers come to similar conclusions. For example, the apparently relatively high N utilization after mineral fertilization and liquid organic fertilizers does not take into account that a certain amount of N comes from N_t soil reserves, which is usually not included in the calculated N inputs. In the range of an equal total N supply and accounting for the N_t soil balance, the results show no remaining differences or even certain advantages of solid organic fertilizers in particular compared to mineral N fertilization in the total N efficiency calculations [157,162,220].

However, with approximately the same level of N supply, clearly different amounts of organic matter were added over time by the fertilizers. Therefore, the calculated values in the annual DM supply by the solid organic fertilizers, with 2.6 t ha^{-1} stable manure and with 2.2 t ha^{-1} of green manure, were much higher than the values with liquid manure supply or the N-mineral fertilization. Consequently, it is not surprising that the C_{org} contents in the soil obtained in the long term and the results of organic matter balancing also led to similar gradations compared to no fertilization (Table 7).

Compared to no fertilization, the soil organic matter content and the humus balance results increased in all fertilization variants. Based on N, a clear ranking was also evident. The highest increase occurred after stable manure, followed with a clearly lower effect by green manure and a steady application of cattle slurry. However, N mineral fertilization still contributed to a minor C_{org} accumulation via the increased crop and root residues. In many other experiments, similar effects of organic and mineral fertilizers on the soil organic matter and N_t contents could be determined [204,215,216,221–224].

The different composition of the fertilizers also influenced the annual values of N mineralization calculated with the CCB model. For stable manure with a relatively high proportion of more slowly available N, an additional annual N mineralization of 30 kg ha^{-1} could be estimated. After green manure, however, considerably higher values and after slurry and N-mineral fertilization, in contrast, very low values in the annual N-mineralization are observed (Table 7).

The obtained values of N mineralization reflect this different composition of the fertilizers investigated quite well. In special incubation tests, reduced N mineralization of conventionally managed soils can thus be determined, which on lower C_{org} contents, for example, are associated with correspondingly reduced amounts of convertible organic substances. In contrast, increased mineralization values on organic test plots are based on their higher contents of convertible organic matter. Soils that have been treated with different fertilizers for long periods of time are therefore also characterized by a very differentiated mineralization and residual capacity [196,221,224–227].

This characteristic behavior in soil organic matter turnover and N mineralization with a continuous supply of fertilizer also had an effect on other soil characteristics investigated. For example, the partly high quantities of organic material applied did not have a negative effect on the pH values of the trial variants. The still widespread view of a negative influence of organic matter on lime supply cannot be confirmed. There are indications of a slightly positive effect as a result of organic fertilization or green manuring, e.g., with legumes, on soil pH values [48,215,222,224,228,229]. For calcium ammonium nitrate, a weak acid effect is already known to be expected [230]. Accordingly, not only in the experiments presented here, a trend towards decreasing pH values after application of a steady N mineral fertilization was also determined (Table 7; see also [215]).

After application, the organic fertilizers in the soil are affected by conversion and decomposition processes. The nutrients are subject to release at different rates, depending on their incorporation into the organic matter of the fertilizers. N and P are plant structural elements, they are mineralized in a similar sequence as part of organic matter turnover, while K, as a functional element, is not incorporated into the cell substance and is therefore subject to much faster availability [193,205]. As the results show, in the context of soil nutrient dynamics, these processes ultimately lead to a corresponding enrichment of the plant-available nutrient contents of the soil, which can be detected in adequate proportions by the usual extraction methods (DL, CAL, $CaCl_2$).

The cattle slurry applied had the highest N content of the fertilizers at both sites. Therefore, it is evident that the P and K contents of the soil, with values around 110%, increased only relatively slightly when measured on an N basis. The P was followed by the effect of stable manure, its variants raised to 118%, and green manure, its contents in the soil increased to 130% (=1.46 mg P 100 g^{-1}) in comparison with no fertilization. K was enriched from green manure to 119% and from stable manure to 139%, resulting in an increase in soil contents by 3.44 mg K 100 g^{-1}. Since only a selective N supply was obtained by the N mineral fertilization and also an increased nutrient removal had to be taken into account due to the yield effect, the contents of P and K in the soil of the trial variants dropped to 88–95% of the supply level of the non-fertilized variants (Table 7).

In many other long-term experiments in conventional and organic agriculture, organic fertilizers lead to positive effects on the soluble P and K contents of the soil [48,206,215,222,223,231–233]. A short overview of further experimental results can be taken from [88]. After organic fertilization, a stabilization of more soluble P fractions and a reduction in less soluble fractions occur, especially in soils with higher pH values [234].

Although relatively small amounts of P and K entered the soil with the slurry fertilization, there was probably a more pronounced nutrient transfer to the subsoil (90–200 cm) due to the liquid application than with the other organic fertilizers. Compared to the variants without fertilizer application, a relatively high P translocation of 146% occurred after slurry fertilization. In contrast, the solid organic fertilizers tended to reduce the P and K in the subsoil. The nutrient enrichment was obviously particularly pronounced at 90–200 cm depth in the market crop systems on light soils.

Furthermore, the variants in which a decrease in the P and K contents in the topsoil was determined by N-mineral fertilization are to be emphasized. However, at the same time, a high selective P enrichment in the subsoil was observed, which at 142%, was similar to that in the slurry variants. A precise fixation of the values is often not possible due to the high variation and the relatively small amounts of nutrients to be evaluated. According to studies by [235], a similar effect was, for example, found between the translocation of N and P in long-term experiments. Other experiments also revealed a translocation of P and K from organic fertilizers, such as slurry [231,232,236–238].

In contrast, a relatively clear assignment of the measured changes of reactive N in the topsoil, in the subsoil and by leaching is possible. After organic fertilization, the mean N_{min} contents increased between 2.8–9.1 kg N ha^{-1} in spring and relatively uniformly by only 4.9–6.4 kg N ha^{-1} in fall (Table 7). The amounts of N transferred to the subsoil and the calculated leaching amounts were also at relatively low levels for these fertilizers. Only a small increase in these values to 110–120% after stable manure and to 135–160% after cattle slurry compared to no manure application was recorded. Other studies also reported comparatively low amounts of N translocation to the subsurface after organic fertilization [215,239].

Through the mineral N fertilization, the values of N translocation and leaching have developed quite differently. In accordance with the relatively favorable performance of these variants in the N balancing, the N_{min} values increased by 15.3 kg N ha^{-1} in spring and even by 37.3 kg N ha^{-1} in fall, which was between 137–202% compared to no fertilization. Due to these increased values of reactive N in the profile up to 90 cm soil depth, the amount of N shifted up to 200 cm depth was also 392% higher with 22.7 kg N ha^{-1} and the calculated leaching amount with 10.9 kg N ha^{-1} $year^{-1}$ even increased to 573% compared to the variants without fertilization (Table 7). With these values, especially the fall N_{min} values, which are mainly affected by a transfer in the winter half-year, were 31–32 kg N ha^{-1} higher between the variants with N-mineral fertilization than those with organic fertilization. The additionally translocated N-quantities were between 18–22 kg N ha^{-1} and annually leached N-amounts were 9–10 kg N ha^{-1} higher than after long-term organic fertilization.

Moreover, on the sandy soils these determined values of translocation and leaching were higher than on the site with the heavy loam soils, although a comparatively lower fertilization level with N was realized (Figure 1). A clear difference can be seen between the organic fertilizers and the N mineral fertilization in the depth profile.

The use of the ram core probe proved to be particularly effective in accurately recording the potential for nutrient loss. At this point of investigation, for example, it was important to take samples well below the rootable soil horizon as this was the only way to clearly determine the loss potential of nutrients. In the experiments, it could be shown that plant nutrient removal of, for example, N was given on the in-depth loam soil down to a soil depth of approximately 150 cm and on the sandy soil down to a soil depth of 100–120 cm. Comparative studies using similar bore methods, lysimeters or suction cups taking into account shallower soil depths are therefore hardly suitable for reliably evaluating farming systems in terms of their transfer and loss potential of N. Such results must therefore be questioned critically [57,58,240–242].

Extensive calculations of the results of the second half of the experiments also showed that at both sites the relations between the NH_4-N and NO_3-N fractions shifted clearly in favor of the more rapidly moving NO_3-N fraction, especially in the measured N_{min} values in fall and in the depth profile after many years of N mineral fertilization. This confirmed observations that the reverse process had been found as a result of conversion to organic farming by a temporary increase in the NH_4-N fraction [43,156,243,244].

High rates of translocation and leaching after N mineral fertilization can also be inferred from other summarized studies [31,239,245]. In a more than 20-year trial on loamy sand in eastern Germany there was a remarkable high shift of N down to 300 cm soil depth after high N mineral fertilization compared to extremely high organic fertilization. The losses were particularly high in the variants that additionally received no irrigation and therefore had a significantly lower yield performance [215].

Based on the clearly different nutrient availability between the tested organic fertilizers, it is most remarkable that the fall N_{min} values, the translocated and the leached N amounts were at a comparatively very low level. In reviewing quantities, it is also important to consider the amount of reactive N that is available at any given time. These amounts are obviously at a very low level in pure organic fertilizer systems, even when observed over a long period of time. Therefore, depending on the application focus, these organic fertilizers are very well suited for organic farming. This has also proven to be the case for green manure, which was tested for the first time in the long-term and is also used today in the form of transfer mulch or in cut and carry systems [246,247].

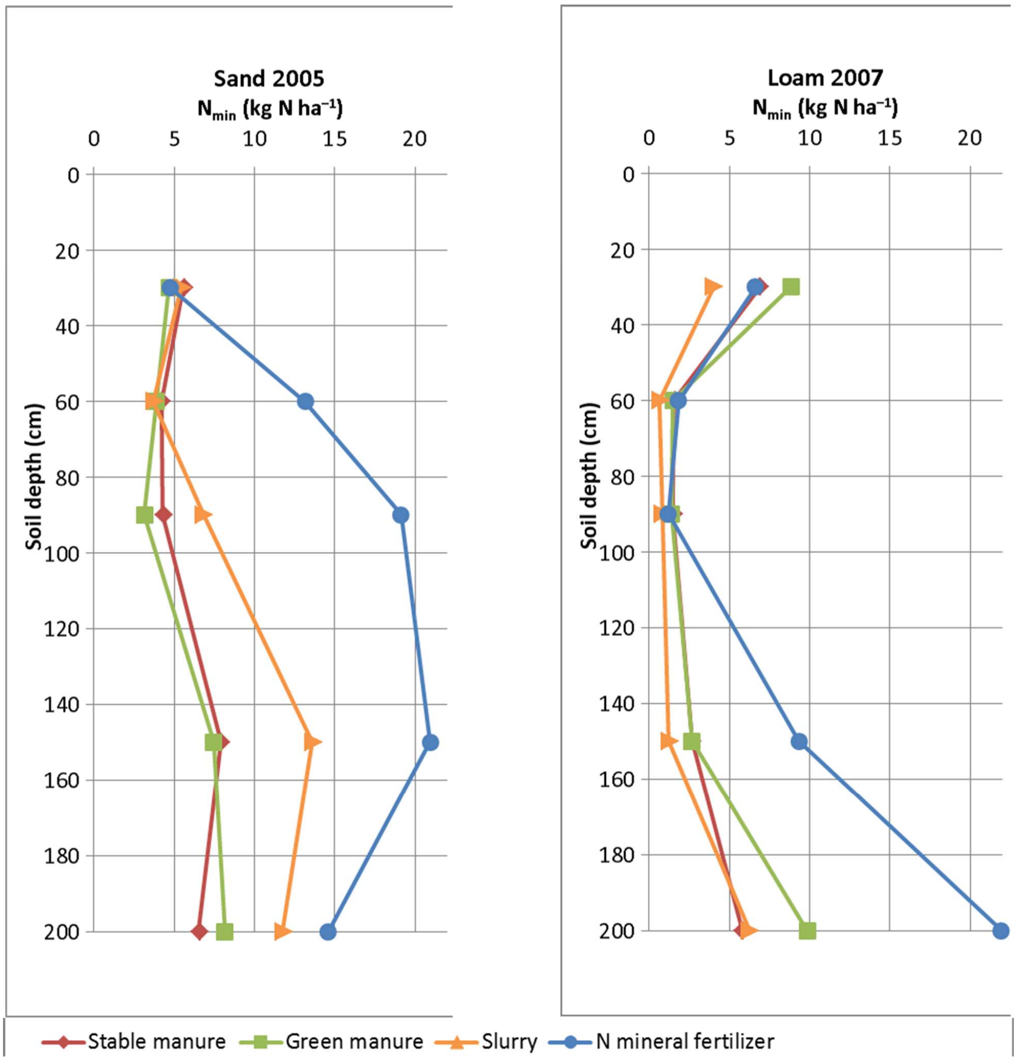

Figure 1. Development of N_{min} amounts after continuous fertilization with stable manure, green manure, slurry, and N-mineral fertilization in the soil depth profile after 14–16 years of long-term experiments (sandy soil: ms = ±2.33 kg N ha^{-1}; loamy soil: ms = ±1.49 kg N ha^{-1}).

As soon as direct fertilization with N mineral fertilizers is applied at a comparable level, the reactive N content in the soil already increases sharply in early spring and over a longer period of time. In this case, the N supply in early spring is better for the plant growth and an early yield formation than after usual organic fertilization. In the further course of plant growth, however, this results in a significant increase in the N content of plant products, which can contribute to a corresponding increase in baking quality in the case of wheat, but also to high nitrate levels, e.g., in potato tubers.

10.2. Extended Comparison of Site and Fertilizer Type Using the Example of the Nutrient Nitrogen

In a more detailed study, the influence of fertilizers on sandy and loam soils was shown using the example of seven characteristics of N in comparison to the GE crop yields achieved (Figure 2). The average N supply via the organic fertilizers is between 76 kg and 85 kg N ha^{-1} on the loam soil and on the sandy soil with 62–74 kg N ha^{-1} on a slightly lower level. However, in both places the values are quite comparable among themselves. This is also true for the level of N mineral fertilization, while on the loam soil a somewhat higher N supply of 120 kg N ha^{-1} was applied due to the better soil conditions.

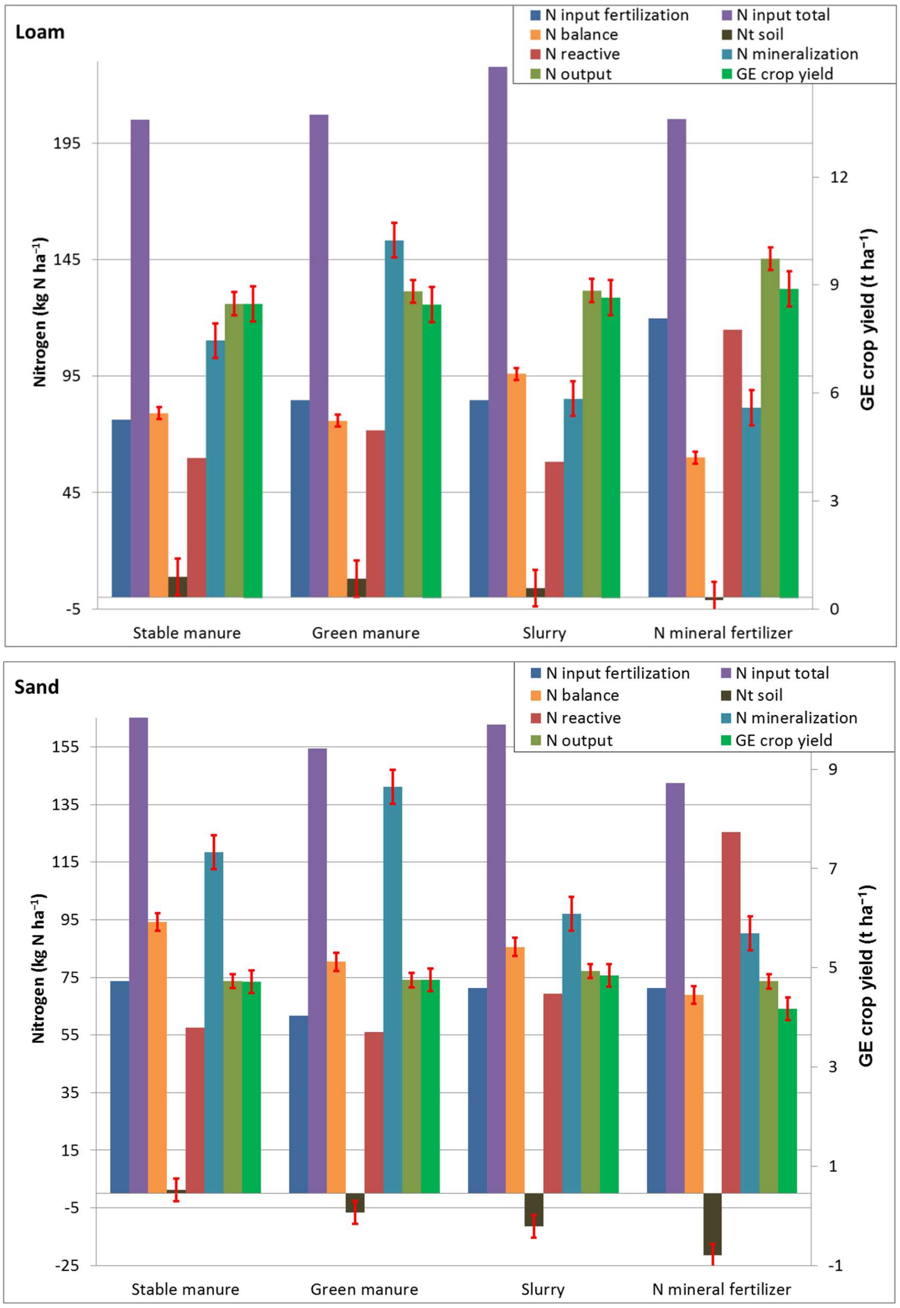

Figure 2. Comparison of some balance criteria, mineralization and reactive N, GE yield, and standard deviation(s) between long-term applied fertilizer types on loam soil (**top**) and sandy soil (**bottom**).

Since the mineral N fertilization at both sites had a negative influence on the legume proportions in the clover grass and also a correspondingly unfavorable effect on the N_2 fixation of the legumes, the determined total N supplies of 205–228 kg N ha^{-1} $year^{-1}$ are finally at the same level. In this way all listed fertilizer types are quite comparable with each other. On the sandy soil these values are slightly lower and were on a comparable annual level overall with 155–168 kg N ha^{-1} for the organic fertilizers as well as with 143 kg N ha^{-1} for the N-mineral fertilizer.

As the average yields between the fertilizers used have leveled off in the course of the long-term trials, no major differences can be seen in yield levels between the crop species of the standardized crop rotations calculated (Figure 2). For example, GE yields on the loam soil were at relatively comparable levels with 8.2 t ha^{-1} for stable manure and green manure, 8.3 t ha^{-1} for slurry, and 8.6 t ha^{-1} for N mineral fertilizer. At the site with sandy soils, GE crop yields were close to each other with 4.2 t ha^{-1} for the stable and green manure variants and with 4.3 t ha^{-1} after continuous slurry application, while at this site yields after N mineral fertilization were estimated at a slightly lower level with 3.7 t ha^{-1} GE.

If comparable fertilizer regimes with similarly high total N supply are continued until soil organic matter equilibrium has been reached, yield differences between the organic fertilizers should hardly occur anymore. Crop yields will then become largely aligned at higher levels, although soil organic matter contents may show clear differences between fertilizer variants. As the results show, the different growing conditions and N_2 fixation levels of the crop rotation legume portions contributed to this equalization of yield levels in organic long-term experiments. In cropping systems with solid organic fertilizers and a correspondingly lower proportion of reactive N in the soil there was higher legume N_2 fixation over the long term than in fertilizer types with a higher reactive N content, such as slurry or mineral N fertilization. In contrast, in conventional long-term experiments with different fertilizers, but without legume cultivation in the crop rotations, such equalization of the yield levels can apparently not be observed to the same extent [248–250].

Although there are no major differences in yields after a long trial period, the N uptake of the plants in the trials tested here was based on the direct availability of N. Usually, only moderately high values are present after stable manure application, while higher values of directly available N are determined after green manure and especially after slurry treatments. After N-mineral fertilization, on the other hand, very high values of directly available N are found in the year of fertilizer application [162,251].

Based on these differences, there is a stronger N uptake after slurry and N mineral fertilization, so that the N concentrations of these plants are at a somewhat higher level. Compared to the yield effect, the calculated N removals of the crop species increase more strongly after slurry and especially after N mineral fertilization (Figure 2). After stable manure, hardly any N enrichment is possible, after green manure and slurry application, only a slightly higher uptake was given, while after N mineral fertilization, a clearly forced N uptake was made possible compared to the yield effect.

Summarized experimental results of [197] also showed the following ranking of the increase in N concentrations in potato tubers by continuous application of different organic fertilizers: compost < manure < liquid manure < commercial organic fertilizers. In contrast, the contents of P could hardly be influenced. Based on a good availability of K, the K concentrations in the tubers could be clearly increased by all types of fertilizer.

As a result of the described effects of mineral N fertilization on N contents, calculated N removals, and also on crop vitality loss due to disease and reduced lodging resistance, which led to negative yield effects in cereal crops, the relative distances between N removals and GE yields turned out to be particularly large compared to organic fertilizers at both experimental sites (Figure 2).

In addition to the directly available N from the N_{min} reserves of the soil and the NH_4-N release from fertilizers in the application year, the yield formation of the crop species in organic farming is covered in particular by the amount of annual N mineralization. The amount of mineralization is derived from the decomposition of long-term added organic substances via fertilizers, green manures, crop and root residues as well as the old reserves of the decomposable soil organic matter fraction [89,193,205]. From the results, the special importance of N mineralization for the organic farming is visible. Other sources additionally contribute to yield formation, but they are often only of supplementary importance.

As can be seen from the level of N mineralization on the loam soil, yield formation is essentially already covered from this mineralization level, which is particularly true for the solid organic manures (Figure 2). The green manure shows the highest values of N mineralization at both sites as, unlike the stable manure, it contains a high proportion of easily convertible organic matter.

Compared to the solid organic fertilizers, a much lower N mineralization was calculated for both sites after steadily applying slurry and even more reduced after N mineral fertilization. As can be seen from the results on the loam soil, the directly available N sources after application are of greater importance for these fertilizers. For example, cattle slurry, even from organic farming, is known to have a plant-available NH_4-N content of 40–60%, while the remaining residual N shows only low mineralization values. Hardly any additional mineralization was calculated for the calcium ammonium nitrate applied. A directly effective N content of nearly 100% can be assumed [162,199,200,251].

If these available N sources are added up in the context of a fertilizer requirement calculation, it is possible to determine from the extensive calculations that the N uptake of the crop species was sufficient to cover the yield formation for each fertilizer investigated. This general agreement can also be seen from the mapped values of N mineralization and the estimated N amounts in the year of application resulting from the N inputs of these fertilizers (Figure 2).

On the sand site, in contrast, other limiting factors have to be considered. Based on the calculated level of N mineralization and the other available N sources, the nutrient amounts at this site would have been sufficient for a much higher yield level in some cases. In addition to the less favorable conditions of a light sandy soil, a lack of water may also be essentially responsible for these results. On the light soil, 436 mm of precipitation per year were measured on average during the trial period (291 mm from April–September), while on the deep loamy soil the precipitation was 686 mm and 398 mm, respectively [43].

Another indicator of insufficient yield formation as a result of water shortage or other factors, such as deficiencies in the supply of basic nutrients, is, for example, the elevated N_{min} values after harvest on the sandy soil. In addition, the high N balance and the reduced nutrient efficiency levels at this experimental site contribute to these effects. By comparing the balance criteria as well as the listed reactive N portions, the reduced N efficiency at the light site can be tracked very accurately (Figure 2). While these values are roughly at the same level between the two sites, the fertilizer input, total N input, and N removal are, in some cases, much higher on the heavy soil for all fertilizers. As a result of these differences, a higher nutrient efficiency of about 13–14% is realized on this trial site.

As can be seen from the results on N-mineralization presented here, the relatively low values of N-mineralization in the cattle slurry, and especially in the N-mineral fertilization, must take into consideration that a part of these values is based on a net decomposition of the N contained in the soil organic matter, which is especially true for the light site (Figure 2). There was 11 kg N ha^{-1} released from the N_t soil fund each year in the slurry variants and as much as 22 kg N ha^{-1} when N mineral fertilizer was applied. The values of N mineralization of these variants partly consist of a decrease in the soil organic matter quality, so that the C:N ratios in the soil have also changed accordingly.

In contrast, particularly in the variants that were continuously supplied with organic matter from the solid fertilizers, there was a net accumulation of N in the soil despite the high values of N mineralization, which could be estimated at 8–9 kg N ha^{-1} year^{-1} on the heavy soil site. In order to evaluate the N balances obtained, these values in the change of the N_t contents of the soils can be additionally accounted for: addition of negative N_t balances and subtraction of positive values.

When these corrected gross N balances are compared with the determined amounts of N_{min} in the fall, as well as in the soil profile down to a depth of 200 cm, including the estimated N leaching amounts (=reactive N; Figure 2), there is a relatively good correspondence for the organic fertilizers, although in most cases the values of the N balances are somewhat higher than those of the reactive N.

However, in the variants supplied with N mineral fertilizers, the values of the corrected N balances on the sandy soil are about 34 kg N ha^{-1} and on the loam soil even 54 kg N ha^{-1} lower than the estimated amounts of reactive N. With these results it is evident that obviously the N balances do not reflect the total sum of reactive N. It can be assumed that in the case of the easily soluble N-fertilizer these N-portions, which are particularly responsible for losses over the winter, translocation, leaching and for the climatically harmful trace gases (N_2O), are 25–50% higher than the N-gross balances determined in the usual way.

In contrast, after conversion to organic farming and discontinuation of mineral N fertilization, a relative decrease in the NO_3-N portion in the N_{min} fraction is observed, especially in deeper soil layers. The nitrate removal from the subsoil is then obviously dependent on the extent and duration of the cultivation of deep-rooting plant species, such as alfalfa [156,252]. In this context, rooting depths are up to 200 cm for alfalfa, up to 150 cm for red clover, and approximately up to 90 cm soil depth for the frequently used grass species (meadow fescue, timothy, perennial ryegrass) [253]. The periodic cultivation of the particularly deep-rooted forage legumes with the highest possible population shares, although they themselves contribute to the N supply via N_2 fixation, appears to be a kind of general reinsurance that the translocation and leaching losses of nutrients can be kept at a very low level.

In field vegetable crop rotations with under-sown legume grass and other organic farming variants, in which a greening with catch crops was carried out in fall and winter in particular, there was also a significant reduction in N with deep roots in the subsoil down to a soil depth of approx. 250 cm. In contrast, the conventional trial variant with partly high N mineral fertilization, but without green cover, contributed to reduced deep growth even of the main crops and high N contents in the subsoil [245,254]. However, since the organic variants in these experiments apparently suffered from insufficient nutrient supply, a certain deficiency may also have contributed for the forced deep growth of plant roots. It is well known that common organic farming usually contributes to an increase in rooting of the deeper soil layers [255].

When considering long periods of time, it can therefore be concluded that the reactive fraction of N can indeed be fundamentally influenced by the choice of fertilizer. All solid fertilizers tested, and to a somewhat lesser extent also the liquid organic fertilizers, resulted in relatively low proportions of reactive N in the soil. In contrast, N mineral fertilization in the form of calcium ammonium nitrate resulted in a much higher amount of reactive N (measured as N_{min} amounts in the fall after harvest, in the depth profile and as a loss quantity due to leaching). Consequently, as N_{min} levels then rise sharply in the fall and subsequently also in the subsoil, the risk of N loss increases continuously. The experiments have shown that no treatment variants, such as leaving the by-products on the fields (straw) or cultivation of catch crops, are suitable in the long run to substantially reduce or limit these extremely unfavorable effects of N-mineral fertilization (see [186,256]).

10.3. Comparison of Productivity, Soil Fertility and Environmental Impact of Widespread Average Manifestations of Organic Agriculture from Practice and Experiments

From statistical surveys and special studies on cultivation forms of organic farming in agricultural practice, it can be roughly assumed that, on average, typical cultivation conditions have a legume share, especially from clover, alfalfa and grass species and a low proportion of grain legumes between a total of 30% and slightly more than 40%, a predominant cereal cultivation around 48% and a root crop share (including corn, oil crops, field vegetables) around 12% (see Table 3). The use of organic fertilizers is on average around 0.5 LU ha^{-1}, which corresponds to an N supply (without additional purchase) of about 30 kg N ha^{-1} year^{-1}. Certain variants from long-term studies and continuous field trials mentioned below and described in more detail in Table 1 fit these cropping combinations [8,9,43–47,49,50].

Based on the trial results of forage and market crop variants, organic fertilization from an animal husbandry intensity of 0.5 LU ha^{-1} and a cultivation extent of legumes around 33% in the trials presented here, a relatively high agreement with the average situation in the agricultural practice of organic farming in Germany or in Central Europe can be established (Table 8).

In the last decades, the cultivation methods of organic farming established in agricultural practice have been investigated several times by different authors with respect to their effects on farm soil fertility and potential environmental impacts [16,18,26,29,31,34,51,54,73,254,257]. Summarized comprehensive results from recent farm surveys are listed comparatively in Table 8 (nutrient balances include results from Germany, Austria, Great Britain and Norway, nutrient supply classes only include results from Germany, due to low comparability).

As a central reference value, the supply of organic fertilizers in agricultural practice is somewhat higher than the range of values of the trial variants presented here (no purchased fertilizers were provided in the trials, and a small amount of purchased fertilizers is common practice on the farms). In these long-term trials, values in legume N_2 fixation ranging from 78 kg N ha^{-1} on the loam soils to 56 kg N ha^{-1} on the sandy soils were obtained under the reported extent of legume cultivation (plus a small proportion of leguminous catch crops). In the trials, the highest values in the proportion of legumes in the legume-grass mixture and also the highest values in legume N_2 fixation are obtained at this intensity level. The range determined in practice is somewhat comparable with the values of the experimental variants of the light soils (Table 8).

The nutrient and soil organic matter balances are in the range of the documented trial results, both in terms of the calculated mean values and the ranges of variation. On average, the farms are characterized by N balances between 20–40 kg N ha^{-1}, −6 kg P ha^{-1}, −26 kg K ha^{-1} and a supply level of soil organic matter (humus balance) around 142 HEQ ha^{-1}. On the basis of quite comparable soil nutrient contents, the mean values of 32 organic farms from the state of Saxony in Germany, for example, were an N balance of 32 kg ha^{-1}, a P balance of −10 kg ha^{-1}, a K balance of −60 kg ha^{-1}, and a humus balance of +150 kg HEQ ha^{-1} [30]. Raussen et al. [51] determined a P balance of −10 kg ha^{-1} and a K balance of −50 kg ha^{-1} for organic farming in the state of Hesse (Germany). However, in these nutrient balances, which were not determined at the farm level, the N balances had been estimated at −20 kg ha^{-1}.

According to very extensive data material from many federal states of Germany, [29] calculated a mean humus balance of +143 kg HEQ ha^{-1} (supply level C) with a range of variation in −178 HEQ to +720 HEQ ha^{-1}. The mean and range of variation in the soil organic matter balances determined in the trials presented here are approximately at comparable levels (Table 8). This organic management resulted in a small increase in the soil organic matter contents between +0.035% C_{org} on the sand and +0.144% C_{org} on the loam soil in the trials compared to the previous conventional management. These values can also be largely confirmed by findings in organic practice [35,63,134,160].

Such average cropping conditions described resulted in N removals, which in agricultural practice are approximately between 87–123 kg N ha^{-1} [29–31,61,73]. In the experiments, depending on the cropping system the N amounts harvested ranged from 38–114 kg N ha^{-1} on the light soil and from 72–180 kg N ha^{-1}year^{-1} on the loam soil. These nutrient removals corresponded to GE yields of around 4.3 t ha^{-1} on sand and around 8.0 t ha^{-1} on loam soils.

Table 8. Mean values, range of variation, and supply classes [(1)] of important characteristics of nutrient management and soil fertility of organic farming systems of intensities around 0.5 LU ha^{-1} on loam and sandy soils in long-term trials and from farm surveys of agricultural practice.

	Organic Fertilization	Legume N_2 Fixation	N Balance	P Balance	K Balance	Mg Balance	S Balance	Soil Organic Matter Balance [(2)]	P_{CAL}	K_{CAL}	Mg_{CaCl_2}	pH-Value
	[kg N ha^{-1}]	[kg N ha^{-1}]	[kg N ha^{-1}]	[kg P ha^{-1}]	[kg K ha^{-1}]	[kg Mg ha^{-1}]	[kg S ha^{-1}]	[kg HEQ ha^{-1}/Class]	[mg P 100 g^{-1}/Class]	[mg K 100 g^{-1}/Class]	[mg Mg 100 g^{-1}/Class]	Class
Long-Term Trials												
Loam soils												
Forage crop systems (by-products removed)	37	87	±0	−17	−120	−10	0	+158 C	3.9 C	7.4 C	6.7 B = C	5.6 B
Market crop systems (by-products remain, clover-grass mulching)	33	66	+87	−7	−14	−1	8	+433 D	4.3 C	11.6 D	7.9 B = C	5.7 B
Sand soils												
Forage crop systems (by-products removed)	32	56	+14	−10	−89	−4	7	+82 C	5.2 D	10.4 D	2.3 A = B	4.9 B
Market crop systems (by-products remain, clover-grass mulching)	30	55	+83	−2	−1	1	12	+214 C	7.0 D	10.7 D	2.4 A = B	5.0 B
Mean values (ms)	33	66 ± 3.0	46 ± 3.4	−9 ± 2.1	−56 ± 15.5	−4 ± 2.0	7 ± 1.4	+222 C ± 18.0	5.1 ± 0.19	10.0 ± 0.56	4.8 ± 0.35	5.3 ± 0.05
Organic Farm Surveys												
Minimum	0	7	−23	−16	−84	−10	0	−340				
Maximum	166	136	137	26	134	90	16	925				
Mean value (ms)	44 ± 23	57 ± 14	28 ± 11	−6 ± 6	−26 ± 20	11	7	142 ± 42				
Class A (%)								3	13	7	1	5
Class B (%)								9	27 #	27 #	12 #	28
Class C (%)								45 #	36	37	23	41 #
Class D (%)								31	16	18	24	20
Class E (%)								12	8	11	40	6

[(1)] Supply classes: undersupply (A, B), optimal supply (C) and oversupply (D, E) according to VDLUFA in Germany; #: supply classes considered optimal in organic farming [109]. [(2)] Soil organic matter (humus) balance ~C_{org} difference (kg ha^{-1} $year^{-1}$): there is a close correlation of r = 0.744 ($p < 0.001$) between humus balance of STAND method and C_{org} difference [112].

Although there was a small increase in the soil organic matter content in all variants with 0.5 LU ha^{-1}, in accordance with the relatively intensive previous cultivation the N_t content still decreased by 20–29 kg N ha^{-1} $year^{-1}$ on the sandy soil and also to a small extent on the loamy soil. In contrast, the amounts of N translocated and affected by leaching are extraordinarily low on these variants, which is also confirmed from survey studies in agricultural practice and points to the advantages of these types of cultivation for environmental and, in particular, water protection [31,34]. The same is generally true for climate-relevant trace gases [73,258], which have also been studied in some of these long-term experiments [259,260].

It is remarkable that even as a result of the average intensity shown, the translocation and leaching of nutrients remain at a very low level. This is also true for the determined variants of forage and market crop cultivation, although there are large differences in the supply of organic materials between these cultivation systems. Although considerably higher soil organic matter balances were calculated for the market crop variants, only very small differences in the calculated yields between forage and market crop systems were found. Since the negative effect of a steady straw application decreases over time, slightly higher yields are then generally obtained on the pure market crop plots. The reason for this is the improved values in N_t and C_{org} contents, higher values of soluble basic nutrients in the soil and the higher N mineralization of these areas.

The calculated complete nutrient balances also show clear differences between these cropping systems, which has been pointed out in previous studies [40,41]. However, in these results, the proportion of recycled nutrients due to repeated mulching of the clover-grass growths must be considered (see [184,261]), and therefore the balances only seem to assume such high values. Calculation attempts to completely exclude mulched clover-grass growth from the balances (see [69]) consistently led to unrealistic results. However, if only 30–50% of the nutrients in the clover grass growths are accounted for according to certain experimental calculations, it is possible to realize verifiable and comparable results in the nutrient balances with the forage cultivation variants.

Total N inputs to the market crop areas were reduced by 17–33 kg N ha^{-1} lower N_2 fixation values caused by the permanently mulched legume-grass mixtures. In addition, deductions of the resulting recycled N by the clover-grass crops of about 50 kg N ha^{-1} $year^{-1}$ and of N losses by ammonia gas emission of about 10 kg N ha^{-1} $year^{-1}$ have to be taken into account.

According to studies by [262], ammonia losses after mulching are at the same high level. The legume N_2 fixation was reduced by 114 kg N ha^{-1} (=−36%) and the legume portion in the clover grass from 73% to 58%. Loges et al. [263] come to similar results with different forage legume-grass mixtures. According to our own observations, even large amounts of mulch were removed from the soil surface, especially by nocturnal earthworm activity, within short time periods of about 30 days after placement, and incorporated into the soil for mineralization. Thus, ammonia losses occur only in a relatively short period of time.

Investigations by [264,265] have shown that, depending on the C:N ratio of the organic material, approximately 20–50% of the nutrients contained in N, P and K are taken up by the succeeding plants or found in soluble form in the soil by late fall. Through mulch fertilization alone, also as a cut and carry system, marked yield increases were observed in some cases for the cultivated crop species.

If the nutrient balances are corrected in the presented form, the N balances of the market crop variants drop clearly, but the negative P and K balance values are also further reduced by corresponding amounts. For example, on the loam soil the N balance can be reduced from 142 kg N ha^{-1} to 63 kg N ha^{-1} if high clover grass growth rates are taken into account, and on sandy soils the N balance can be reduced from 101 kg N ha^{-1} to 80 kg N ha^{-1} if a relatively low clover grass growth is taken into account in the corresponding variant. The balances corrected in this way reflect the remaining reactive N-amount much better, as then both the translocated N-amounts and the effects on the organic matter and N_t content of the soil between the two listed cropping systems are quantitatively comparable and calculated correlations show a higher statistical reliability. This approach has indeed improved the technical validity of the nutrient balances. However, the calculation of the balances is associated with a higher effort, so that it has been omitted in Table 8.

Very close statistical regressions between the calculated nutrient balances and the annual change in certain soil nutrient contents have already been determined in previous studies [47,88,206]. With respect to the nutrient N, it was calculated for the loam soil that a culmination balance range of around 50 kg N ha^{-1} was required to ensure at least no further changes in the soil N_t contents (r = 0.936, $p < 0.001$); on the previously highly fertilized sandy soil, even around 100 kg N ha^{-1}, were actually needed (r = 0.969, $p < 0.001$) [39]. At N balances below these values N_t contents decrease, as is also the case in the average intensity level of these summarized studies (see Table 5); at higher values they increase in the soil. By continuing the assumed average intensity, the C_{org} and N_t contents of the topsoil would change as follows in 10 years, using the forage cropland as an example:

- Loam soils: +0.042% C_{org} DM, −0.006% N_t DM.
- Sandy soils: +0.016% C_{org} DM, −0.001% N_t DM.

Based on the results of soil organic matter (humus) balancing, which is very closely related to the change in soil contents when the STAND method is used [112], C_{org} contents would still increase by about +0.090% on loamy soils or by a total of 0.047% C_{org} on sandy soils until a new equilibrium is reached. The expected changes in soil organic matter and N reserves are not particularly large at this average cropping intensity.

For the basic nutrients examined there are also close statistical relationships between the respective balances and the temporal soil change in plant-available nutrient contents. Correlations between the change in different solvent-extracted nutrients, such as P or K, and the calculated nutrient balances have also been established in other long-term experiments [50,88,266]. The use of these mathematical relations in algorithms for the fertilizer determination of basic nutrients is well established in organic farming [267,268].

According to [269], negative P and K balances in a long-term experiment with conventional and organic cultivation variants lead to decreasing contents of these nutrients in the soil. Based on summarized results of [39], P balances may assume a lower limit of −5 kg P ha^{-1} on the loamy soil and at least about +2 kg P ha^{-1} on the more permeable sandy soil without changing the nutrient contents of soluble P in the soil. Since in the comparative trials, clearly more negative P balances were determined at this relatively low intensity, and there was a decrease in the P concentrations in the topsoil at both sites (see Tables 5 and 8). Corresponding to these distinct negative P balances, over the course of 10 years the P_{DL} contents of the topsoil in the forage cropping systems would change in the following way: loam soils −0.85 mg P 100 g^{-1}, sandy soils −1.92 mg P 100 g^{-1} soil. As these clearly negative nutrient balances are also recorded on average in organic farming practice (Table 8), the corresponding soil nutrient contents will continue to decrease in the future if there is no change in the current trend of nutrient management. Similar temporal developments could be confirmed by some surveys in practice. For example, according to [67], the P content decreases by about 0.5–1.0 mg P 100 g^{-1} per decade in the soil of organic farms.

These culmination points between nutrient balances and the soil change could also be determined in studies on the nutrient K. On loamy soils, negative K balances of 50–60 kg K ha^{-1} can exist due to the high resupply, which does not reduce the soluble K contents in the soil. On the sandy soil, however, the values should be at least +10 kg K ha^{-1}, as K is also subject to translocation and leaching to a greater extent in this soil, while the resupply is only relatively low.

As can be seen from Table 8, the K balances in both cropping systems of this average intensity level are clearly negative. In a weakened form, this also corresponds to Mg. In the average of the forage cropland plots, the following change in the K_{DL} contents of the arable topsoil can be calculated for 10 years: loam soils −2.75 mg 100 g^{-1}, sandy soils −1.39 mg 100 g^{-1} soil. Since such negative balances are also widespread in agricultural practice, it can be expected that the K concentrations of the soil will continue to decrease in the future. In this context, there is often a decrease in the highly supplied classes C–E and a corresponding increase in the undersupplied classes A and B [29,95].

A special feature must be noted for eastern Germany in the case of the nutrient S. Based on the high atmospheric supply from earlier decades and S depositions of 11–12 kg S ha^{-1} and balance values around 7 kg S ha^{-1} in the course of the presented trials, a sufficient S supply can be expected, since considerable amounts of S are still available in the deep profile through the plant roots. Even plant species with high S uptake, such as forage legumes and silage maize, could still be sufficiently supplied. Only on sandy soils can it be foreseen that these stocks in the subsoil have already decreased so markedly that the plants are no longer able to use them. Therefore, there is currently no acute danger of a clear S deficiency, even in the practice of organic farming [30]. However, with further decreasing values in the deposition and in the profile subsoil, S deficiency under organic farming conditions can also be expected under the eastern German conditions, as is already the case today in western Germany for certain plant species [270].

The CCB model [89,194] was used to determine the annual mineralization of N. For the loam soil, values between 59–131 kg N ha^{-1}, whilst on the sandy soil the corresponding values were between 62–135 kg ha^{-1} of N mineralization. Taking into account these values of N mineralization as well as the usual characteristics for N fertilizer requirement determinations, the total amounts of nutrients made available for uptake on both soils were in any case sufficient to cover the yield levels achieved on average for the entire crop rotations.

In contrast to N, yield limitations can also occur with the basic nutrients if they fall below certain minimum values of plant available nutrient contents in the soil, as has also been demonstrated under the conditions in organic farming, for example, for the nutrients P and K, as shown by a meta-analysis of many field trials from Germany [271]. However, due to the still relatively high supply of the nutrients P and K (classes C–D, Table 8), these yield-limiting conditions have not yet occurred in the long-term trials presented here.

For the basic nutrients, the annual P and K release through soil organic matter turnover and other processes covered only about 15–30% of the nutrient quantities directly taken up by the growing plants. Therefore, to meet P requirements, a temporary decrease in plant-available nutrient levels during the growing season was estimated to be only 0.4 mg P 100 g^{-1} on sandy soils and no more than 1.0 mg P 100 g^{-1} on loamy soils. For the nutrient K, the calculated decrease was also at a relatively low level of 3–5 mg K 100 g^{-1} soil. Consequently, no deficiency was to be expected for either nutrient in the average of the studies, taking into account the mineralization amount, as the yield-limiting values (class B or A) were not reached or undercut in any case.

However, detailed investigations on the organic farms, and also in the long-term trials presented, have revealed that there is a need for action at various levels of farm-related or inter-farm nutrient management when longer periods of time are considered. According to these results, the proportions of basic nutrients with clear undersupply of up to 15% are still at a relatively low level. In contrast, however, deficiencies in the ability to maintain optimal pH values were found on 33% of the practical field plots (Table 8).

In further investigations in several European countries it has been shown that with increasing age of organic farming after conversion, the available basic nutrients P, K, and Mg, as well as the pH-values of the soil, decrease due to the negative nutrient balances and partly reach yield-threatening low values [20,22,272,273]. According to [274], 86% of the P analyses and 36% of the K values examined in Great Britain are in the deficiency classes. Summarized data from [275] indicate that in the case of P, 3% of the soil analyses in Norway, 37% in Germany, 49% in Austria, and 66% of the analyses in Switzerland are in the deficient range.

For the evaluation of the supply range, however, methods of conventional farming were often used. Since the lower yield level common in organic farming also means that the required basic supplies in the soil, which must at least be available for optimum yield formation, are at a lower level [29,271], the amounts shown so far with deficiency supply may also have been estimated somewhat too high.

Using specially calibrated assessment systems, in which yield endangering areas can be precisely identified both according to the minimum law [96] and by observing basic rules of crop rotation design for organic growing conditions, the following results were obtained in the analysis of 32 organic farms with at least six years of cropping rotation and 810 arable field plots in eastern Germany (Figure 3):

- Under evaluation of 4800 crop years, on average of the farms, potentially yield-limiting deficiencies were found on a total of almost 40% of the arable field plots, mainly as important recommended intervals of cultivation of the crop species in the cultivation sequences were not observed [276].
- Taking into account 10 evaluation criteria in nutrient management, yield-limiting deficiencies were detected on a total of 66% of the field plots: pH value 37%, N balances 18%, humus balances 17%, P contents soil 15%, K contents soil 13%, P balances 13%, K balances 9%, Mg and S balances < 2% [95].

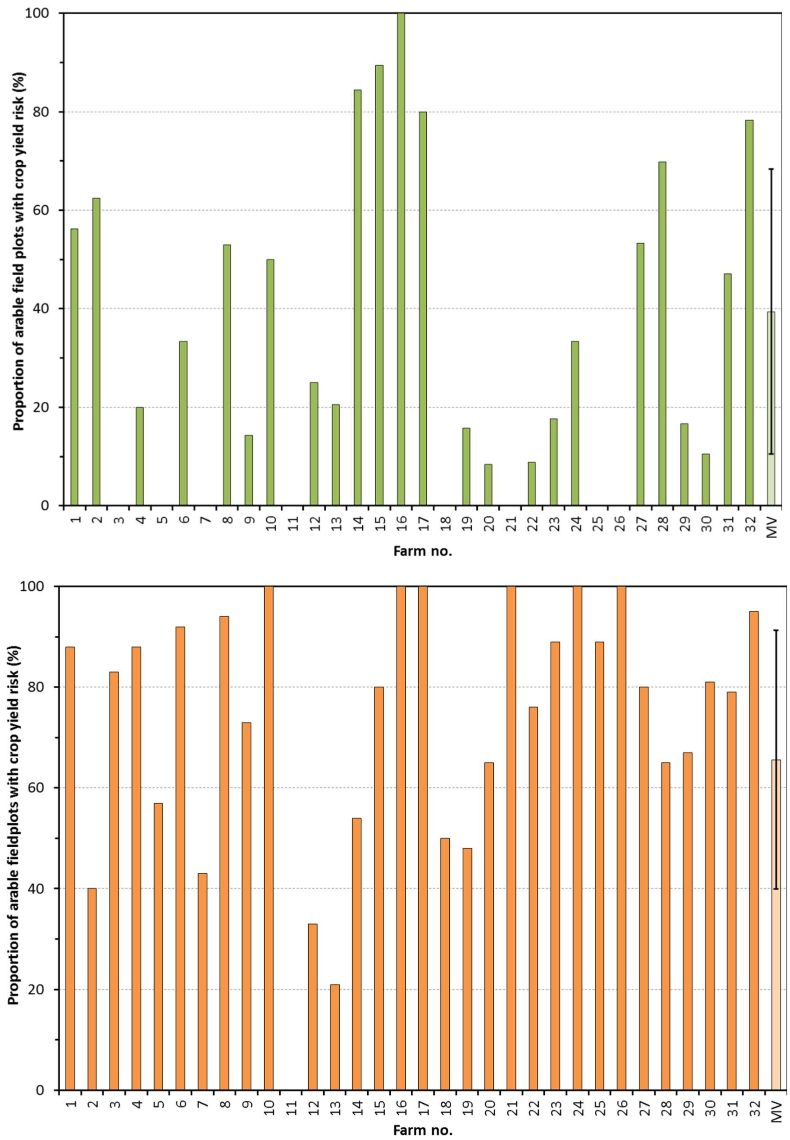

Figure 3. Proportion of yield-limiting field plots per farm due to insufficient intervals of cultivation for potatoes, oilseed crops, grain legumes and/or red clover, alfalfa, and lupine (**top**) as well as in the sum of test characteristics for nutrient management (**bottom**) and the mean values of the farms (MV, including standard deviation).

In the evaluation work field, plot-specific analysis was carried out, which has the advantage over the farm based approach that no arithmetic averaging is carried out, which means that the true extent of both positive and negative management aspects is leveled out and consequently often cannot be detected. On average of the plots, a definite yield loss according to the minimum law of 11% was calculated in comparison to the optimal nutrient conditions with corresponding nutrient classes. On the affected plots the yield loss was 18% (absolute variation 10–32%), caused by at least one and on average 1.9 ($\pm$0.6) factors per arable plot.

Due to the widespread occurrence of stagnant crop yield levels, farmers are also attempting to counteract this with crop management measures common in organic farming, such as increased cultivation of legumes. Higher legume N_2 fixation levels can also temporarily increase yields of subsequently grown non-legumes when N has been a limiting factor. But with parallel increases in nutrient removal then occurring, nutrient balances of P, K, Mg, and S may continue to decline toward inadequate levels. This causes the available reserves of the soil to drop even faster to yield-limiting levels, which can also eventually be seen in reduced N efficiency values. For example, in farm studies by [273], decreasing nutrient balances were determined as a result of increasing leguminous N_2 supplies.

After investigations on the Gladbacherhof in western Germany, attempts were made to counteract the unfavorable yield development by increasing livestock production [107,277]. With an organic fertilization corresponding to 1.1–1.4 LU ha^{-1}, N balances of 75 kg N ha^{-1}, clearly positive P balances around +15 kg ha^{-1} and K balances around +55 kg ha^{-1} were then already calculated in most of the forage crop rotations with 38% legumes. These relatively high values can be explained by the further decline in yields over time and the associated low nutrient removal by the cultivated crops. However, the yield drop was based on other steadily increasing deficiencies in soil nutrient management (including S, P, K, pH value; [278,279]).

It is becoming evident from these examples that, even as a result of increasing intensity of organic fertilization, attention must be paid to all important soil nutrients to ensure that they remain at the optimum level in accordance with the minimum law for yield formation. As a result of suboptimal conditions, the longer the nutrients fall and reach the minimum, the more difficult and costly the subsequent remediation process will be. In phases of strong increase in fertilization, e.g., as a result of stockpiling in livestock farming, the rise in soil organic matter content can also lead to nutrient immobilization in the meantime. As the results show, these relationships around attention to yield losses due to deficiencies in chemical soil fertility play an increasingly important role not only in experimental work, but also in the agricultural practice of organic farming.

11. Concluding Remarks

In the last decades, cultivation forms of organic farming have become more and more widespread, with its importance for food security and soil fertility as well as for environmental impacts consequently increasing more and more. In this article, extensive studies from many farms have been compiled and, in addition, subjected to a more in-depth analysis in comparative presentations with special long-term field trial results.

There was a very high agreement between the investigation results of the practice and the long-term experiments in most of the examined characteristics if, besides site properties, an exact agreement of the cropping structure with the extent of legumes in the crop rotations and the intensity of organic fertilization has been observed. Some differences occurring between practice and scientific publication could be attributed to such causes of errors. The average cultivation structures of organic farming in some countries of Central Europe are characterized by crop rotations emphasizing cereal cultivation, with an average extent of forage and grain legumes of between 30–40% and an application level between about 30–40 kg N/ha from organic fertilizers.

In summary, it can be noted that the trial results described here on the average intensities are also applicable to a wide range of organic practice farms. These farms have a certain amount of animal husbandry and are also characterized by a cultivation that largely corresponds to the type of the mixed farm. These described farms have for a long time therefore considered to be an ideal type of organic farming [280–282].

As a further priority of these summary investigations, it was intended to carefully examine essential production factors of organic farming. In this work, in-depth results from many field trials and practical surveys on short-term and, in particular, the long-term effects of important nutrient management systems, which are more difficult to determine experimentally, were presented. For example, in order to compare fertilizers, a direct presentation of the results of the use of slightly soluble mineral N-fertilizers was also made, enabling a better description and, if necessary, a clearer delimitation of the application spectrum of different types of fertilizers for organic farming.

The nutrient N is also to be regarded as a major yield-limiting factor in organic farming. As a conclusion from the summarized trial results, the following ranking can be manifested for the relative availability of N for plant growth and crop quality:

- N mineral fertilizer > legume portion crop rotation, commercial fertilizer > green manure > cattle slurry > market crop: straw + clover-grass mulch > stable manure > composts.

In the case of equal N supply, this ranking also applies to the N effect in the year of application (according to NH_4-N shares and C:N ratios according to tabular works) and the resulting direct yield effect of the crop species.

However, the longer the different fertilizer regimes are practiced, the more clearly a steadily increasing yield leveling occurs after one to two decades due to the self-regulation of the legume stands and the specific changes in soil organic matter content and soil fertility caused by the fertilization. This temporal yield equalization of such different fertilizer regimes as compost or slurry management after many years of application should be considered one of the major results of this work. However, despite similar high yield effects, there are differences in both the N-containing ingredients of the plant species and in the plant-available N contents of the soil (N_{min}), which persist even after long application. Continuous application of organic fertilizers thereby also affects the other soluble contents of soil nutrients in subsequent rankings (− = decrease):

- P_{DL} content: green manure > stable manure > compost > cattle slurry.
- K_{DL} content: stable manure > compost > green manure > cattle slurry, commercial fertilizers.
- Mg_{CaCl_2} content: stable manure > green manure > cattle slurry (−).
- S_{min} content: stable manure > cattle slurry (−) > green manure (−).

Through this, the corresponding nutrient concentrations can also be influenced, especially in vegetative plant parts, which is particularly true for K. For the basic nutrients, solid organic fertilizers such as stable manure and green manure are well suited to increase their availability in the soil. The contents of S_{min} could only be slightly improved by organic fertilization. This also applies to the availability of Cu, Mn, and Zn. After cattle slurry, green manure and, in the market crop variants, a reduction in S availability had even occurred. Often there is an inhibition of S in the soil, especially if the added fertilizers have low S contents or a wide C:S ratio [43,283,284].

In the direct and particularly the long-term effects on yields, vitality, and susceptibility to disease of the crop species and the quite unfavorable effects on soil fertility, N mineral fertilizers have clearly not given good results when applied under organic farming conditions. Compared to organic fertilizers, N mineral fertilizers are characterized by an extraordinarily higher loss potential, which can be attributed in summary to the following causes:

- High proportion of directly available reactive N in the total N-quantity.
- Clear shift of the NO_3-N:NH_4-N relation in the N_{min} amounts after harvest and in the depth profile in favor of the nitrate fraction, which is characterized by a high mobility, translocation, and leaching.
- By reducing the legume fraction in the periodically cultivated clover-grass mixture by about 40% portions, there is a considerable reduction in N_2 fixation. In addition, a

substantial decrease in deep-rooted plant species in the mixtures has also occurred, accordingly reducing the nutrient retention and mobilization potential from the subsoil (see [285]).

As a clear result, it can therefore be concluded that N mineral fertilization in organic farming is not a fertilizer to be recommended for the many reasons listed. Compared to the high proportion of reactive N, a far higher level of organic fertilization with a corresponding yield effect could even be aimed for within a framework of systematic intensification until a comparable level of reactive N is reached. Compared to this reactive N content, a higher yield level could be better achieved, to a limited extent, by organic manure than by the application of mineral N fertilization. In the context of a sustainable intensification of organic farming, the application of N mineral fertilizer is still therefore not a suitable means [286,287].

In a further focus of investigation, the developments of the yield capacity and in the soil fertility after the conversion and consolidation phase of organic farming crop rotations and cultivation systems were examined. Through many periodic results from long-term trials, observations from practice could experimentally prove that essentially two different tendencies are opposed to each other. At average cultivation intensities, on the one hand, a slight increase in the soil organic matter content can be observed within the first decades after conversion. On the other hand, depending on the site and the intensity of cultivation, there are sometimes longer-lasting decreases in the N_t content and also in the available soluble basic nutrients as well as in the pH values of the soil.

After conversion, it is often common practice that the nutrient levels enriched by intensive conventional pre-farming are initially depleted, which also reduces corresponding negative environmental impacts. However, studies in agricultural practice have shown that, for example, this depleting management has continued 20–30 years after the start of organic farming. It can be concluded that, based on the extensive evaluations from several countries, deficiencies in both nutrient management and crop rotation design are more widespread on organic farms than was previously known.

To a certain extent, improvements can initially be achieved in both the design of optimal crop rotations and in N and organic matter supply by observing appropriate cultivation rules as well as generally applied organic crop management measures mentioned below to strengthen the nutrient cycle [276,288–292]:

- Diversified crop rotations.
- Periodic cultivation of deep-rooting plant species.
- Intercropping.
- Green manuring.
- “Green wave” through steady soil cover.
- Creation of a rich landscape.

However, the investigations have shown that these measures for securing soil fertility and closing the “inner” material cycle (Figure 4, no. 1) are no longer sufficient in the case of the usual organic cultivation methods [29]. Through the annual removal and sale of agricultural products, nutrient losses have occurred which, due to the previously usual nutrient additions, led to often clearly negative nutrient balances and, in the long term, a specific unfavorable change in the nutrient content of the soil. These nutrients are affected to varying degrees.

The supply of the basic nutrients P and K and the pH values, as well as Mg on light soils and S in regions with only a low atmospheric supply, is to be assessed as clearly negative to some extent. In the case of the basic nutrients and lime supply, it is therefore becoming increasingly evident that the nutrient cycles are not closed (Figure 4, no. 2). The extent of nutrient return is usually very low [293]. In order to prevent serious disadvantages in soil fertility and yield capacity in organic farming, the time has come to make efforts to achieve nutrient cycles that are as closed as possible in the long term.

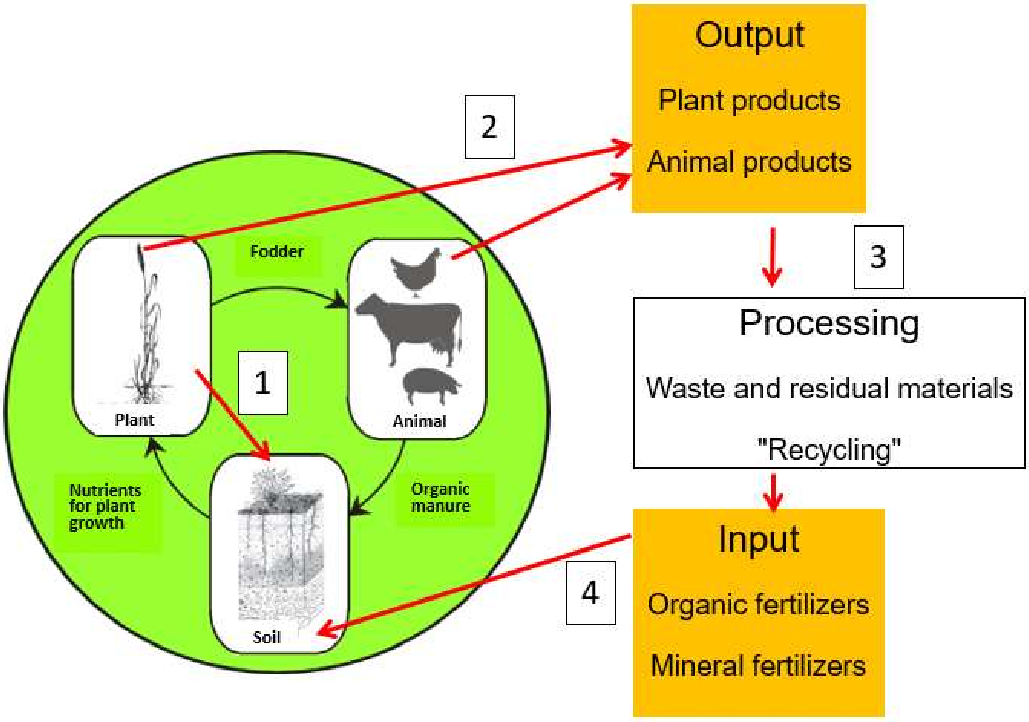

Figure 4. Symbolic representation of the internal and external nutrient cycle (1: Measures for securing soil fertility by closing the internal cycle; 2: By periodically exporting nutrients through product sales, the nutrient cycle is not closed; 3 and 4: A net supply of nutrients must come from newly created fertilizers from the recycling sector).

As a result of the strained situation in the field of limited resources and their "purity", which does not only apply to the situation with the nutrient P [294], other sources for a net supply of nutrients must therefore be developed in the future (Figure 4, no. 3). This includes, first of all, a processing of special fertilizers from the extensive area of wastewater and biowaste in such a way that they can also be accepted, approved and applied in organic farming [295–301]. On this topic, a change in trend has occurred in recent years. On the one hand, there have been increased efforts to identify, test and produce new "clean" fertilizers from the field of treatment and recycling of, for example, biowaste composts and sewage sludge. On the other hand, there has also been a growing awareness in the organic farming sector at both association level and in agricultural practice of the need to intensify nutrient management on the farms (Figure 4, no. 4).

Accordingly, the insufficiencies described, especially in chemical soil fertility, which are largely based on the minimum law, can only be identified and corrected by periodic and field plot-based use of methods of soil testing, nutrient balancing and fertilizer requirement determination, e.g., with the help of PC models specially created for organic farming, in order to be able to ensure a high degree of sustainability on farms in the future. The tools required for this purpose have been available for practical use in organic farming for many years [109,200].

Despite the available extensive results and the arising need for action in practice, these relationships and their effects on soil fertility and yield performance of the crop species have not yet received corresponding attention in the current scientific literature on organic agriculture [117,302–304]. Practice-oriented methods of nutrient management should therefore also be given a higher priority in teaching, training, and consulting in the future. Intensive experimental activity in trials and on farms will also be essential in the future to overcome the obviously existing deficits in research and teaching on organic farming and to keep the tools for practical recommendations in these areas up to date at all times.

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